Rio Tinto Alcan

Kitimat Modernization Project Sulphur Dioxide Environmental Effects Monitoring Program

Program Plan for 2013 to 2018

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October 7, 2014

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Please cite this report as follows:

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Trent University, and Trinity Consultants. 2014. Sulphur Dioxide Environmental Effects Monitoring Program for the Kitimat Modernization Project. Program Plan for 2013 to 2018. Prepared for Rio Tinto Alcan, Kitimat, B.C. 99 pp.

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Executive Summary

This document describes the modeling and monitoring that is planned for the next six years (2013 to 2018) under the sulphur dioxide (SO_2) Environmental Effects Monitoring Program for the Kitimat Modernization Project, and thresholds for increased monitoring or mitigation if warranted based on the monitoring results. Rio Tinto Alcan will implement SO_2 mitigation strategies if the outcomes of monitoring and modeling described in this plan show adverse impacts causally related to SO_2 that are considered to be unacceptable.

The EEM Program is specific to SO_2 emissions from KMP. Non-SO_2 KMP emissions, emissions and impacts from other facilities, and research and development of new indicators or monitoring methods are all outside of the scope of the EEM Program.

The plan distinguishes two types of indicators: key performance indicators (KPIs) which will have quantitative thresholds for increased monitoring or for mitigation, and informative indicators which will provide evidence in support of key performance indicators. The following table presents a synthesis of the indicators described in the plan:

Pathway / Receptor	**Key Performance Indicators (KPIs)**	Informative Indicators
Atmospheric Pathways		Atmospheric SO_2 concentrations Atmospheric S deposition Base cation deposition
Human Health	The health section of the EEM program and KPI will be updated when provincially applied SO_2 ambient air quality guidelines come in effect.	Predicted annual restricted airway responses
Vegetation	**Visible vegetation injury caused by SO_2**	S content in hemlock needles
Soils	**Atmospheric S deposition and critical load exceedance risk** **Long-term soil acidification (rate of change of base cation pool) attributable to S deposition**	Magnitude of exchangeable cation pools (Ca, Mg, K, Na) Time to depletion of exchangeable cation pools (Ca, Mg, K, Na) Base cation weathering rates
Lakes and Streams, and Aquatic Biota	**Water chemistry – acidification**	Atmospheric S deposition and critical load exceedance risk Predicted steady state pH versus current pH Evidence that pH decrease is causally related to KMP SO_2 emissions (ANC, SO_4, DOC) Aquatic biota: fish presence / absence per species on sensitive lakes Lake ratings Episodic pH change Amphibians

Glossary

acid deposition	Transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange
acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, by natural or anthropogenic processes
acid neutralizing capacity	The equivalent capacity of a solution to neutralize strong acids; ANC and alkalinity are often used interchangeably; ANC includes alkalinity plus additional buffering from dissociated organic acids and other compounds
anion	An ion with more electrons than protons, giving it a negative charge, e.g., SO_4^{2-}
base cations	An alkali or alkaline earth metal (Ca^{2+}, Mg^{2+}, K^+, Na^+)
base cation exchange	The replacement of hydrogen ions in the soil water by base cations from soil particles
critical load	A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur, according to present knowledge
dissolved organic carbon	Organic carbon that is dissolved or unfilterable in a water sample (0.45 µm pore size in the National Surface Water Survey)
dry deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via gravitational settling of large particles and turbulent transfer of trace gases and small particles
environmental effects	Impacts on receptors from KMP SO_2 emissions
facility-based mitigation	Sulphur dioxide (SO_2) emission reduction at the KMP facility
F-factor	A simple way to represent cation exchange processes, specifically the proportion of incoming acidity accompanying sulphate that is exchanged in the soil for base cations
informative indicator	Indicators that will provide supporting information for key performance indicators, and may have quantitative thresholds triggering additional monitoring or modelling, but on their own will not trigger mitigation

key performance indicator	Indicators that will have quantitative thresholds triggering additional monitoring or modelling, receptor-based mitigation, and/or facility-based mitigation
liming	The addition of any base materials to neutralize surface water or sediment or to increase acid neutralizing capacity
pH	A measure of how acidic or basic a solution is, on a scale of 0-14; the lower the pH value, the more acidic the solution; pH 7 is neutral; a difference of 1 pH unit indicates a tenfold change in hydrogen ion activity
receptors	Components of the environment assessed for potential impacts from SO_2 emissions from KMP: human health; vegetation; soils; and lakes, streams and aquatic biota
receptor-based mitigation	Receptor-specific actions to reduce exposure or effects, such as air quality advisories in local communities or liming of selected lakes
RIO TINTO ALCAN properties	Core set of contiguous lands owned by Rio Tinto Alcan around the Kitimat Smelter between Haisla Boulevard and District Lot 5469
wet deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via precipitation (e.g., rain, snow, sleet, hail, and cloud droplets)

Abbreviations

Δ	delta, meaning quantitative change (e.g. ΔANC or ΔSO_2)
$<$	is less than what follows
$\leq$	is less than or equal to what follows
$>$	is greater than what follows
$\geq$	is greater than or equal to what follows
[ ]	The concentration, e.g., [SO_2] means the concentration of sulphur dioxide
Al	Aluminum
ANC	Acid neutralizing capacity
Bc	Base cations
BC MOE	British Columbia Ministry of Environment
Ca^{2+}	Calcium
CL	Critical load
Cl^-	Chloride
DOC	Dissolved organic carbon
EEM	Environmental effects monitoring
H^+	Hydrogen
K^+	Potassium
KMP	Kitimat Modernization Project
KPI	Key performance indicator
Mg^{2+}	Magnesium
Na^+	Sodium
NH_4^+	Ammonium
NO_3^-	Nitrate
RTA	Rio Tinto Alcan
SO_4^{2-}	Sulphate
SO_2	Sulphur dioxide
STAR	SO_2 Technical Assessment Report (for KMP)

1.0 Introduction

1.1 PURPOSE AND SCOPE

In 2013 a technical assessment (ESSA et al. 2013) was completed for the Kitimat Modernization Project (KMP), to determine the potential impacts of sulphur dioxide (SO_2) emissions along four lines of evidence: effects on human health, vegetation, terrestrial ecosystems (soils), and aquatic ecosystems (lakes and streams, and aquatic biota).

The purpose of the SO_2 Environmental Effects Monitoring (EEM) Program is to answer questions that arose during the technical assessment, and to monitor effects of SO_2 along these lines of evidence. Results from the EEM Program will inform decisions regarding the need for changes to the scale or intensity of monitoring, as well as decisions regarding the need for mitigation.

The scope of the EEM Program encompasses KMP SO_2 emissions at full production capacity, and this plan focuses on the EEM Program for first 6 years (2013-2018). What is learned during this period will be applied to improve the Program in 2019. Other KMP emissions, research and development related to SO_2 impact measurement and mitigation, monitoring for non-KMP acid deposition and monitoring not specific to KMP SO_2 impacts are all outside of the scope of the SO_2 EEM Program.

This document describes the modeling and monitoring that is planned for the next six years, and decision rules based on quantitative indicator thresholds for increased monitoring or mitigation if warranted based on these results. Two broad categories for mitigations are identified:

Receptor-based – mitigations that would be receptor-specific in design and application, for example air quality advisories in local communities or adding lime to selected lakes

Facility-based – sulphur dioxide (SO_2) emission reduction at the KMP facility

The SO_2 EEM Program focuses on indicators which can be causally related to SO_2 emissions. Two types of indicator are recognized:

Key performance indicator (KPI) – which will have decisions rules (quantitative thresholds) for increased monitoring and for mitigation

Informative indicator – which may have decision rules for increased monitoring, but will have no decision rules for mitigation on their own; instead they will provide evidence in support of key performance indicators

Sections 2 through 6 present indicators and methods for the pathways and receptors depicted in Figure 1. Section 7 describes how a "causal relationship to KMP" will be determined for indicators exceeding their thresholds. Section 8 summarizes the actions that Rio Tinto Alcan will take if unacceptable impacts occur, and Section 9 describes the schedule and content for SO_2 EEM reporting and review.

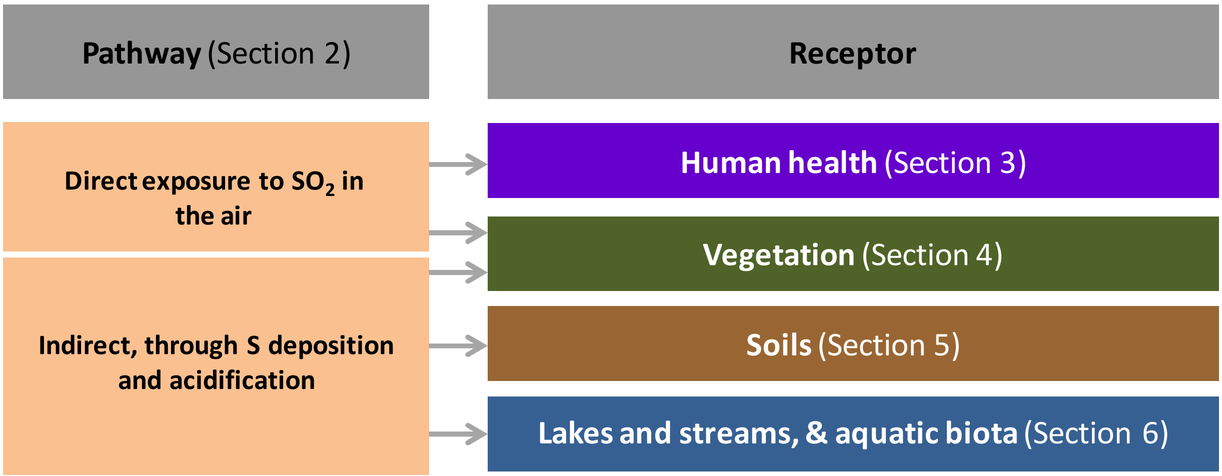

Figure 1. Organization of information in this SO_2 EEM Plan.

1.2 SO_2 EEM FRAMEWORK

Figure 2 illustrates the decision framework for the SO_2 EEM Program. It is divided into three overall phases: pre-KMP, ramp-up and initial KMP operation (2013-2018), and 2019 onward.

The first phase began pre-KMP with the SO_2 technical assessment to determine the potential impacts of SO_2 emissions from KMP. Four potential impact categories were identified, and remain relevant for interpreting monitoring results from the SO_2 EEM Program (Table 1):

Table 1. Impact categories used in the SO_2 Technical Assessment Report

Impact Category	Interpretation
Low	No impact or acceptable impact
Moderate	Acceptable impact but in need of closer scrutiny
High	Unacceptable impact; mitigation action needed
Critical	Extremely unacceptable impact; mitigation action needed

The SO_2 technical assessment predicted that impacts on vegetation would fall into the green (low) impact category, and that impacts on human health, soil, and water and aquatic biota would fall into the yellow (moderate) impact category. The SO_2 EEM Program will determine whether these predictions were correct, and if EEM results indicate that actual outcomes under KMP for any of the receptors will fall into higher impact categories than predicted, describe the decisions rules for action.

In addition, the SO_2 EEM Program will answer questions that arose during the technical assessment (presented in Appendix A). The answers will result in one of three possible outcomes for the receptors:

- The pre-KMP assessment *over*estimated or accurately estimated the impact category. In other words, the impact category predicted in the assessment was either too high, or correct. In the framework, this situation is represented by a "thumbs up".
- The pre-KMP assessment *under*estimated the impact category. In other words, the assessment was overly optimistic – represented in the framework as one or two "thumbs down", depending on the implications of the underestimation of impacts.
- It is unclear whether the assessment underestimated or overestimated the impact risk – represented in the framework as "thumbs down" with a question mark.

The second phase occurs in 2013 to 2018, from KMP ramp-up through to the first years of full operation. It is focused on learning, through regular evaluation of results designed to provide:

- Evidence that the technical assessment *under*estimated the impact category ( ) **and/or** that the impacts are (or are expected to be) high ( ) or critical ( ).
  This will require mitigation and an escalation in either the frequency or extent of monitoring, or both.
- Evidence that the assessment correctly or *over*estimated the impact category ( ), or *under*estimated the impact category ( ) **but** the impacts are (or are still expected to be) low ( ) or moderate ( ).
  This will require no mitigation, but may require modifications to monitoring.
- Unclear evidence either way due to lack of time for effects to be manifested (e.g., to observe that a lake is acidifying) ( ), and the impact category is still estimated to be no higher than moderate ( ).
  This will require no mitigation, but may require modifications to monitoring, either to increase the frequency or number of monitoring locations, or both.

Annual SO_2 EEM Program reports will be produced during the first 6 years to convey results as well as any mitigation that has been undertaken during the preceding year. Annual monitoring plans for the next year will also be developed based on these results.

The third phase begins in 2019, when a report will be produced that synthesizes what has been learned during the first 6 years and assesses which questions have been sufficiently answered and which have not. Based on this report a decision will made about what monitoring should continue, and the frequency of reporting. The SO_2 EEM Program is expected to evolve over time according to what is learned.

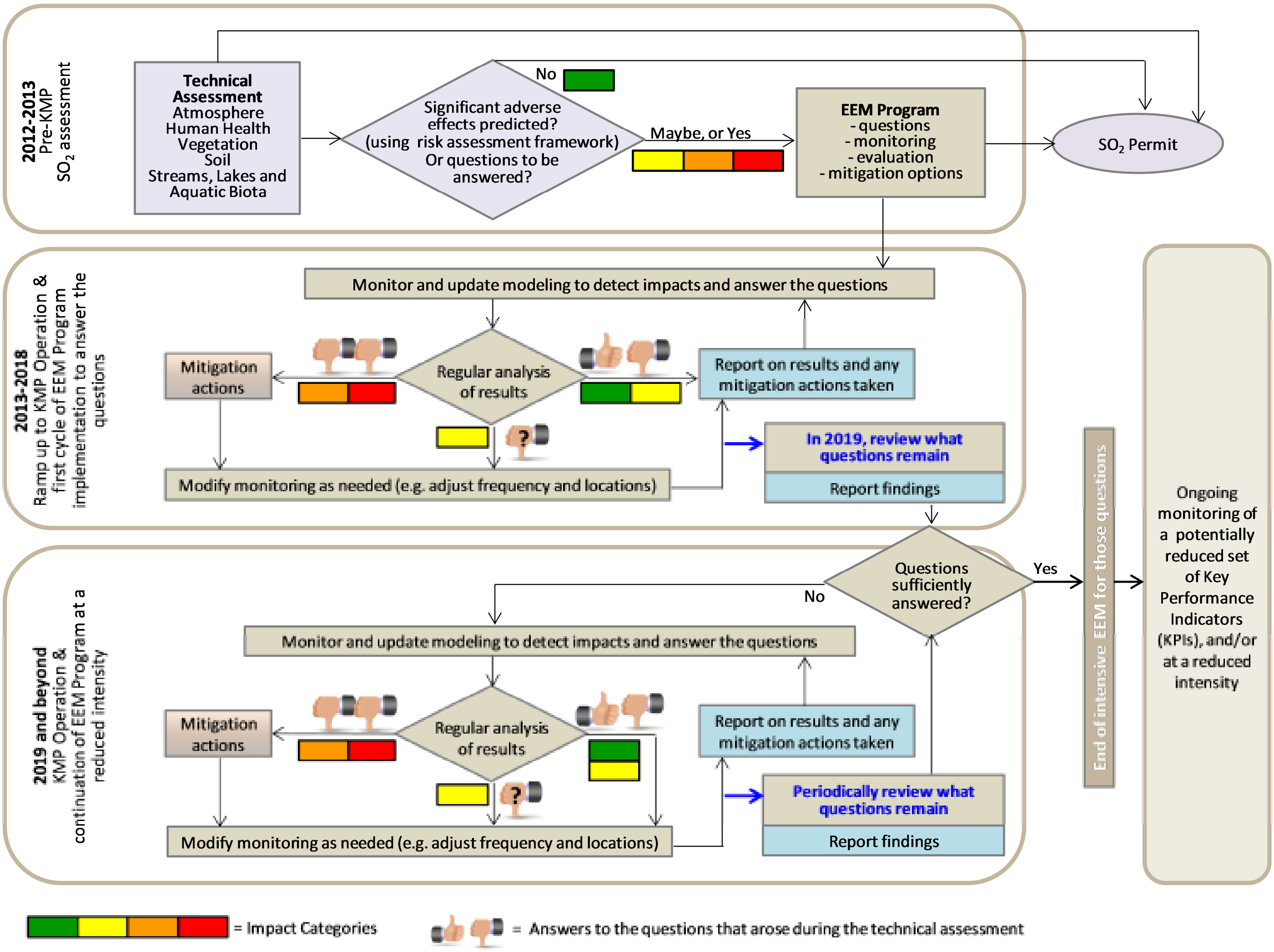

Figure 2. SO_2 EEM framework for KMP.

1.3 DECISION RULES

The cycle within the second phase (2013-2018) of the framework in Figure 2 involves a set of quantitative, threshold-based "decision rules" as illustrated in Figure 3. Thresholds for increased monitoring are lower than thresholds for mitigation, and thresholds for receptor-based mitigation are lower than thresholds for facility-based mitigation. If receptor-based mitigations are not feasible, or are implemented but found to be ineffective, facility-based mitigations will be implemented.

Results of the synthesis and comprehensive review in 2019 will inform decisions about:

- which KPIs and informative indicators should be monitored in 2019 and beyond and at what level of intensity,
- modifications to monitoring methods,
- refinement to KPI thresholds (decision rules), and
- the timeline for the next comprehensive review.

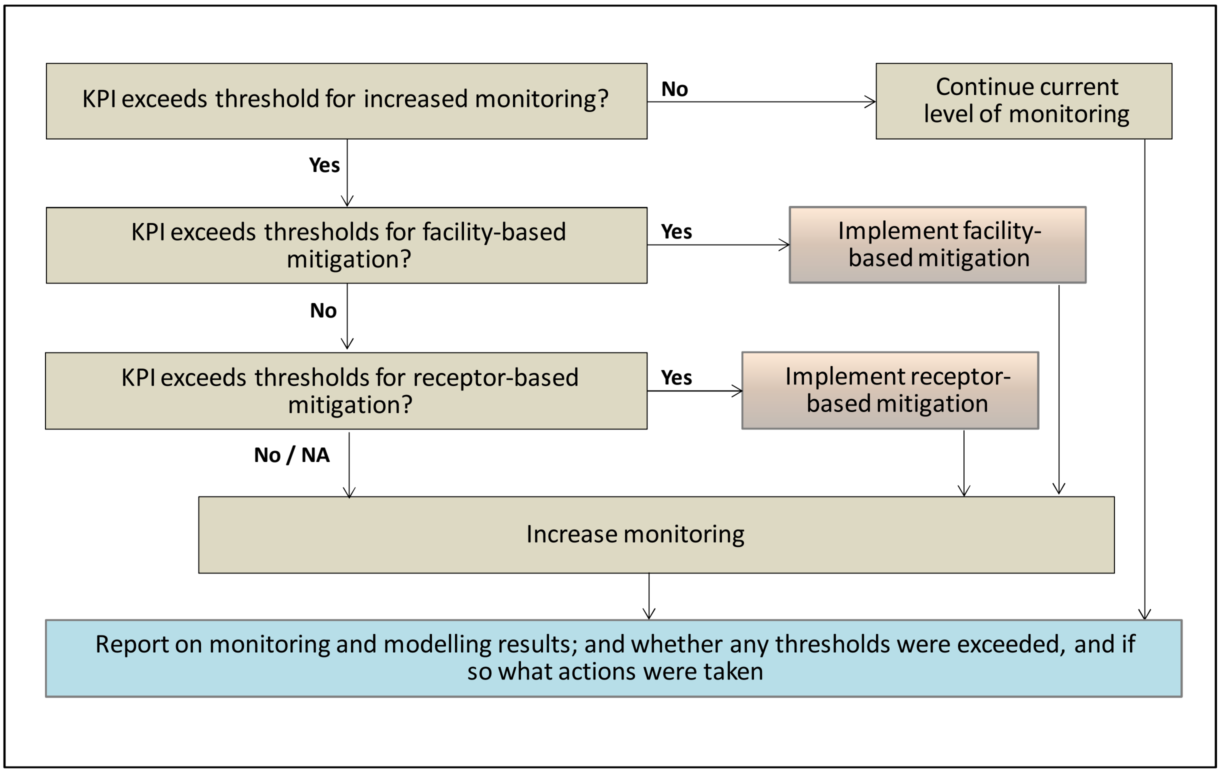

Figure 3. Decision tree for quantitative thresholds of key performance indicators.

2.0 Atmospheric Pathways

2.1 INDICATORS

Table 2. Informative indicators for atmospheric pathways.

Informative indicators	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Atmospheric SO_2 concentration	- Not applicable; will support KPIs and informative indicators for the receptors	- Predicted annual restricted airway responses (3-year rolling average) - Visible vegetation injury caused by SO_2 - Atmospheric S deposition and critical load (CL) exceedance risk
Atmospheric S deposition	- Not applicable; will support KPIs and informative indicators for the receptors	- Atmospheric S deposition and critical load (CL) exceedance risk - Long-term soil acidification attributable to S deposition - Water chemistry - acidification
Base cation deposition	- Not applicable; will support critical load (CL) modelling	- Atmospheric S deposition and critical load (CL) exceedance risk

2.2 METHODS

Table 3. Overview of methods for calculating informative indicators for atmospheric pathways.

Informative indicators	Method overview
Atmospheric SO_2 concentration	Continuous analyser measurements of SO_2 air concentrations from Haul Road, Whitesail, Riverlodge, Kitamaat Village and possibly also Lakelse Lake, as well as the MOE-operated station at Terrace
Atmospheric S deposition	Wet deposition monitoring stations at Haul Road and Lakelse Lake Estimation of dry deposition of S (gaseous S using continuous analysers and pilot testing of passive samplers; particulate S using a filter pack; requires ancillary meteorological monitoring)
Base cation deposition	Wet deposition monitoring and modelling based on data from Haul Road and Lakelse Lake

2.2.1 Atmospheric SO_2 concentration

Sampling locations:

- Essential locations for continuous samplers: Haul Road (fenceline), Whitesail (upper Kitimat), Riverlodge (lower Kitimat), Kitamaat Village (Haisla)).[1] Monitoring at the KMP Camp should also be continued until the analyser is relocated to Lakelse Lake; and then continuous SO_2 monitoring will occur at the new Lakelse Lake site. In addition, MOE will establish a continuous sampler station at Terrace.[2]

Sampling timing, frequency and duration:

- Maintain operation of continuous analysers through 2018 (this assumes that KMP will be fully implemented and at steady-state operations by the end of 2017).

Monitoring protocols and sampling methods:

- Continue to follow the monitoring protocol for continuous analysers including maintenance, calibration, and data collection and quality review.

How and when monitoring data will be evaluated:

- Using continuous analyser data from 2014 to 2018, compare measured concentrations to post-KMP concentrations modelled for the STAR (completed in the first quarter of each year from 2015 to 2019). This timeline assumes that KMP will be fully implemented and at steady-state operations by the end of 2017.
    A. Post-KMP Monitoring Data Study:
        1. Collect and Quality-Assure 12 months of post-KMP emissions data
        2. Collect and Quality-Assure 12 months of SO_2 continuous monitoring data and meteorological data for corresponding time period.
        3. Model actual emissions from 12-month period using the CALPUFF modeling system (including CALMET for new period) using STAR methods
        4. Compare modelled results to monitoring data
    B. Refine CALPUFF Modelling Methods (if the Monitoring Data Study does not show desirable agreement between model results and monitoring data):
        1. Identify model refinement options
        2. Test each option individually to determine effect on model performance.
        3. Define refined CALPUFF model methods based on Step 2 tests
        4. Run refined CALPUFF model for 12 months post-KMP actual emissions
        5. Compare refined CALPUFF model results to monitoring data to confirm overall improvement in model-monitor agreement

[1] The number and location of continuous monitoring stations is subject to finalization in 2018.

[2] Four lines of evidence will provide insights on spatial distribution of SO_2: 5-6 continuous samplers measuring actual SO_2 concentrations, CALPUFF modeling of SO_2 concentrations, S content in hemlock needles, and passive samplers.

2.2.2 Atmospheric S, base cation and chloride deposition

Deposition monitoring will include S, base cations and chloride. The SO_2 technical assessment analyses for predicting critical load exceedance in soils and surface water assumed that deposition of base cations was zero. This was a conservative assumption, as non-marine base cation deposition would increase critical loads and reduce estimates of exceedance.

Sampling locations:

- The NADP site at Haul Road and the proposed site at Lakelse Lake, noting that Lakelse Lake provides the most relevant data to define background base cation precipitation chemistry.
- Regional observations may be supplemented with existing observations from western North American networks, and regional maps of precipitation volume.

Sampling timing, frequency and duration:

- Establishment and continued monitoring at two NADP stations providing data for 3+ years to evaluate background S, base cation and chloride deposition. In this respect, Lakelse Lake will provide the most valuable data.

Monitoring protocols and sampling methods:

- Wet deposition monitoring will be carried out by the NADP following standard NADP network protocols for sample collection, handling and analysis (http://nadp.sws.uiuc.edu). The analysis of wet deposition samples will include sulphur (S), nitrogen (N), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}); as well as chloride (Cl^{-}).

How and when monitoring data will be evaluated:

- S deposition maps will be generated, as was done for the KMP SO_2 Technical Assessment Report (Figure 7.6-5 in ESSA et al. 2013)
- Base cation precipitation chemistry maps will be used to revise regional critical load and exceedance maps to incorporate base cation deposition.

2.2.3 Additional studies

2.2.3.1 Passive Samplers

Consideration is also being given to the use of passive samplers to monitor atmospheric SO_2 concentrations at a broader suite of locations, to increase the spatial coverage of data collection for this indicator.

Sampling locations:

- It is essential that the passive samplers in the pilot program be co-located with continuous monitoring stations to ensure they correlate well (r $\geq$0.8) with continuous SO_2 monitors (as such the pilot program is dependent upon reliable operation of continuous monitors).

Sampling timing, frequency and duration:

- Examine the results of the passive monitoring conducted in 2011-2012, to inform development of protocols for 2015 trials and future expanded monitoring in the humid environment of the study area. Conduct a pilot program for passive sampling in 2015. If the pilot program is successful, implement at a larger scale in summer of 2016, 2017 and 2018, expanding to include near- and far-field locations to capture a spatial gradient of air concentrations.

Monitoring protocols and sampling methods:

- Follow the protocol for the passive sampling pilot program in 2014. If the passive samplers are proven effective, develop a revised passive diffusive SO_2 monitoring program by the first quarter of 2015 to augment continuous SO_2 analysers.

How and when monitoring data will be evaluated:

- Passive sampling data from 2015 will be compared with continuous analyser data to assess the accuracy of passive samplers.
- If a full-scale passive sampling program is implemented, data from 2016 to 2018 will be used to evaluate the relative distribution of CALPUFF modelled concentrations compared to the distribution of measured concentrations at the passive samplers.

2.2.3.2 Dry Deposition Estimation

The method for estimating dry deposition will be developed in 2015.

2.2.3.3 Ambient Air Network Rationalization

A rationalization process for ambient air monitoring stations (number and location) will begin in 2015.

2.2.4 Summary of Atmospheric Pathway actions, 2013-2018

Table 4. Schedule of work on the atmospheric component of EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Atmospheric SO_2 Concentrations – Continuous Analysers	Maintain existing 4 continuous SO_2 analysers. Assess and compare [SO_2] at Haul Road vs KMP Campsite.	Maintain existing 4 continuous SO_2 analysers.	Maintain 4 continuous SO_2 analysers. Compare to model output. Develop a protocol approved by BC MOE to assess the location of continuous analysers and agree on a strategy and timeline for potentially relocating station(s) to more representative locations.	Maintain 4 continuous SO_2 analysers. Compare to model output. Implement the strategy for station locations approved by BC MOE in 2015.	Maintain 4 continuous SO_2 analysers. Compare to model output. Implement the strategy for station locations approved by BC MOE in 2015.	Maintain 4 continuous SO_2 analysers. Compare to model output.
Atmospheric SO_2 Concentrations – Passive Diffusive SO_2 Monitoring	–	Write up 2011-2012 passive monitoring results; use to inform design low cost pilot program with non-TEA based samplers at least 3 sites to see if they correlate well with continuous SO_2 monitors.	Implement pilot program.	If (and only if) pilot program shows good correlations with continuous monitors, then develop revised passive diffusive SO_2 monitoring program to augment SO_2 analysers.	If methodology proven to be effective in 2015 pilot, conduct passive monitoring	If method proven to be effective in 2015 pilot, conduct passive monitoring program.
Wet Deposition – S , Base Cations, Chloride	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake). [In 2019, compare 2013-2018 data to model output, and assess number of rain chemistry stations.]
Dry Deposition	–	Determine entity to develop method for estimating dry deposition using existing data.	Develop and apply the method, to see if this is a significant data gap. Relocate Campsite KMP ambient air and meteorological station to allow for estimating dry deposition at Lakelse Lake (or in 2016, as per the row for [SO_2]).	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations.	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations.	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations [In 2019, compare 2013-2018 data to model output.]
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

3.0 Human Health

3.1 INDICATORS AND THRESHOLDS

The period between 2014 and 2019 is an interim period for baseline air quality data collection to support the establishment of a health indicator for SO2 emissions. As an interim metric, a dose – response health risk metric is used to inform the EEM program of the health risks associated with KMP derived SO2 emissions. Following 2019 or when a provincially approved SO2 ambient air quality guideline is established, both section 3 and table 5 of the EEM program will be updated to include the new air quality guidelines and associated SO2 management actions.

In support of the development of a health based key performance indicator, the Kitimat ambient air station monitoring network will undergo a review and rationalization process in 2015 to ensure that the monitoring stations are representative of KMP SO2 emissions (please see table 4).

Rio Tinto Alcan Kitimat will also participate in an air quality advisory system for SO2 when it is developed by the BC Ministry of Environment.

Table 5. Interim Informative indicator for human health and Key Performance Indicator that will based on a Provincially approved air quality guideline

Informative indicator	Threshold for increased monitoring	Indicators to be jointly considered
Predicted annual number of SO2-associated respiratory responses (3-year rolling average)	Not applicable	Atmospheric SO2 concentrations

Future Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
The health section of the EEM program and KPI will be updated when provincially applied SO_2 ambient air quality guidelines come in effect.[3]			Should there be non-attainment of the guidelines once in effect and following 3 years of applicable data collection, emission reduction will be managed in accordance with section 8 of the EEM plan.[4]	Atmospheric SO_2 concentrations

The health section of the EEM program and KPI will be updated when provincially applied SO_2 ambient air quality guidelines come in effect. The Ambient air data collection to support the future KPI will commence when the Smelter reaches full metal production capacity. Should there be non-attainment of the guidelines once in effect and following 3 years of applicable data collection, emission reduction will be managed in accordance with section 8 of the EEM plan. The choice for attainment of the air quality guideline will be based on a scientific process using tools such as dispersion modeling.

[3] Ambient air data collection to support the KPI will commence when the Smelter reaches full metal production capacity (anticipated in 2016).

[4] The choice for attainment of the air quality guideline will be based on a scientific process using tools such as dispersion modeling.

3.2 METHODS

Table 6. Overview of method for calculating the informative indicator for human health.

Informative indicator	Method overview
Predicted annual number of SO_2-associated respiratory responses	Repeat on an annual basis the calculations conducted in the STAR, under the same baseline assumptions, but using air dispersion modelling refined based on the SO_2 monitoring network and updated estimates of the Peak-to-Mean ratio under Post-KMP conditions.

3.2.1 Predicted annual number of SO_2-associated respiratory responses

The analysis will be conducted according to the following process:

1) Air dispersion modelling will be repeated annually for the same near-field locations as were studied in the STAR (Upper and Lower Kitimat, Kitamaat Village, Service Centre).
2) One or more monitoring stations will be chosen to generate estimates of the Peak-to-Mean ratio in the Post-KMP context. The peaks will be calculated as the highest 5-minute average within each hour. A distribution for the peak-to-mean ratio in the form of a binned histogram will be used in later calculations.
3) The refined air dispersion model output and the updated Peak-to-Mean ratio will be used to generate health risk estimates (annual respiratory airway events) exactly as they were previously in the STAR. The baselines assumptions from the STAR will be applied (e.g., exercise frequency and location, indoor versus outdoor exercise).
4) Each year starting with the third year, the rolling three-year annual average will be compared to the results from the STAR.

3.2.2 Summary of Human Health actions, 2013-2018

Table 7. Schedule of work on the human health component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Atmospheric SO_2 concentration	–	–	Increase accessibility of ambient air quality data to the community. Report on SO_2-associated predicted airway responses.	Report on SO_2-associated predicted airway responses.	Report on SO_2-associated predicted airway responses.	Report on SO_2-associated predicted airway responses.

4.0 Vegetation

4.1 INDICATORS AND THRESHOLDS

Table 8. KPI and informative indicator for vegetation.

Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Visible vegetation injury caused by SO_2	More than occasional symptoms of SO_2 injury outside of Rio Tinto Alcan Kitimat properties, causally related to KMP Action: assess ambient air data, meteorological data and KMP SO_2 production data to find the potential causes; and increase visual inspection frequency to annual	Not applicable – there are no reasonable receptor-based mitigations	Severe & repeated[5] symptoms of SO_2 injury outside of Rio Tinto Alcan properties causally related to KMP, including species of economic or social/traditional importance, <u>or</u> symptoms of SO_2 injury causally related to KMP at long-distance (>15km) monitoring locations Action: reduction in SO_2 emissions	- Atmospheric SO_2 concentration - S content in hemlock needles - Atmospheric S deposition (specifically, wet deposition)

Informative indicator	Threshold for increased monitoring[6]	Indicators to be jointly considered
S content in hemlock needles	An increase of more than 1 standard deviation (from pre-KMP baseline data)[7] in 20% of the sites for 3 consecutive years, causally related to KMP Action: assess ambient air data, meteorological data and KMP SO_2 production data to find the potential causes; and increase visual inspection frequency to annual	- Atmospheric SO_2 concentration - Water chemistry - Soil chemistry - Atmospheric S (wet) deposition

S content in hemlock needles will be used to validate the air modelling, and could be replaced by passive monitors if the pilot described in Section 2 is undertaken and proves effective.

[5] "Severe" means more than 50% of the leaf area is necrotic due to SO_2 exposure on more than 50% of the plants of a single species at an inspection location outside the RTA boundary at the inspection time in late summer (the last 2 weeks of August to the first 10 days of September). It would take at least 2 years (2 late-summer inspections) to determine if the damage seen the first year is "repeated".

[6] Thresholds for increased monitoring are not applicable. This indicator will assist with interpretation of results for the visible injury KPI.

[7] Based on historical monitoring of S in vegetation (1989-2011) (Table 9.2-1 in the STAR (ESSA et al. 2013)).

4.2 METHODS

Table 9. Overview of methods for calculating the KPI and informative indicator for vegetation.

Key performance indicator	Method overview
Visible vegetation injury caused by SO_2	Visual inspection for SO_2 injury every 2 years

Informative indicator	Method overview
S content in hemlock needles	Yearly chemical analysis of S content in needles

4.2.1 Visible vegetation injury caused by SO_2

Sampling locations:

- Areas with existing vegetation surveys (Figure 8.4-1 in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013)).
- Additional locations where critical loads in soils are predicted to be exceeded (from the KMP SO_2 Technical Assessment Report).

Sampling timing, frequency and duration:

- Visual inspection and evaluation will occur every other year[8], near the end of the growing season (late August to early September). The inspection frequency will be increased to annual if the threshold for increase monitoring is reached.
- Frequency and duration after 2018 to be determined in 2019 based on results to 2018.

Monitoring protocols and sampling methods:

- According to visual inspection protocols documented in Laurence (2010).
- A list of vegetation species in the study area that have been reported to be sensitive to SO_2 will be incorporated into a checklist on the field survey forms for visual inspection. During the annual inspections, the checklist will also be used to determine the presence of species that may be sensitive to SO_2 (see Appendix B).

How and when monitoring data will be evaluated:

- Data from 2014 to 2018 will be used to determine whether the health of vegetation is significantly affected compared to the condition at locations remote to KMP.
- Diagnosing injury to vegetation due to air pollutants is aided by two factors: specific symptoms and pattern of injury, and the species injured.

[8] Visual surveys could potentially also be done during 'in-between' years if coincident with sampling hemlock needles for S content.

- o Hydrogen fluoride (HF) (gaseous F) causes symptoms at the margins of broadleaf plants or the tips of needles or blade-leaf plants (such as gladiolus). SO_2 generally causes symptoms of interveinal chlorosis or necrosis on broadleaf plants. It can cause tip necrosis similar to HF on conifers. It may also cause some marginal chlorosis, but that is generally accompanied by interveinal symptoms as well. The pattern of injury is generally marginal for HF and interveinal for SO_2. Injury due to SO_2 often has a more bleached appearance than that due to HF.
- o Plants differ in sensitivity to the pollutants as well. Plants such as gladiolus, Hypericum, mugo pine, cherry, and scouler willow are sensitive and diagnostic for HF. Plants such as Rubus, Acer, and Phaseolus are sensitive and diagnostic for SO_2.

How to determine the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

There are two possibilities:

i. The actual concentrations and associated exposures (concentration x time) are in excess of the concentrations and exposures predicted in the STAR
ii. The vegetation at the site is more sensitive than the literature indicated

The following steps would determine the quantitative reduction necessary in exposure:

1. Co-locate an atmospheric monitor (or a passive monitor, if the passive monitoring pilot is successful) with the vegetation inspection/sampling site(s) where the injury has been observed to determine the actual exposures that are occurring at that location. If the exposures are greater than predicted in the STAR, we will use CALPUFF to determine necessary emission reductions to reduce the exposure to the acceptable levels.
2. If the exposures are within the range predicted in the STAR to occur without causing injury, then the vegetation apparently is more sensitive than reported in the literature. In that case, new thresholds would be calculated based on monitored exposures at locations where effects were within the acceptable range, and modeling studies would be used to determine the reductions in emissions necessary to reach those new thresholds.

4.2.2 S content in hemlock needles

Sampling locations:

- In locations where continuous and passive samplers are operating and at vegetation sampling and inspection sites (Laurence 2010).

Sampling duration and frequency, and essential years and times:

- Samples will be collected near the end of the growing season from mid-August to mid-September (Laurence 2010), for at least the first three years, and longer if warranted based on these results.

Monitoring protocols and sampling methods:

- Monitoring and sampling will be done according to current procedures in use for annual and biennial vegetation sampling protocols (Laurence 2010).

How and when monitoring data will be evaluated:

- Chemical analysis will be conducted by Rio Tinto Alcan and analysed and interpreted in the winter.
- The results will be reported to MOE in March, in time to adjust sampling and inspection for the next growing season if needed.

4.2.3 Summary of Vegetation actions, 2013-2018

Table 10. Schedule of work on the vegetation component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Vegetation Survey	–	Add checklist for presence / absence of sensitive species on field survey form; conduct visible injury survey. Continued vegetation sampling as per Laurence (2010).	–	Visible injury survey. Continued vegetation sampling as per Laurence (2010).	–	Visible injury survey. Continued vegetation sampling as per Laurence (2010).
S Content in Hemlock Needles	–	Samples collected near the end of the growing season from mid-August to mid-September.	Sampling from mid-August to mid-September.	Sampling from mid-August to mid-September.	Sampling from mid-August to mid-September, if warranted from results in 2014 – 2016.	Sampling from mid-August to mid-September, if warranted from results in 2014 - 2016.
Sensitive Ecosystem Mapping (applies to vegetation, soils, and water receptors; listed just once here to avoid repetition)	–	Review Predictive and Thematic mapping to see if there are sensitive ecosystems within the plume not covered by the existing network of vegetation, soil and surface water sampling sites.	–	–	–	–
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

5.0 Soils

5.1 INDICATORS AND THRESHOLDS

The first KPI for this receptor is prediction-based: measured soil chemistry data and measured S deposition data will be used as inputs for updated modeling of critical loads, to determine the spatial distribution and magnitude of exceedance of critical loads of acidity for forest soils. Results will reveal the *extent* of expected impact (i.e. how large an area might be affected) and the *level* of exceedance (i.e. the magnitude of deposition greater than critical load). The second KPI is observation-based: soil chemistry data in selected plots will be tracked to determine actual change in soil base cations over time. For both KPIs, if the thresholds for receptor-based mitigation are reached, and receptor-based mitigations are applied but prove ineffective, facility-based mitigations will be implemented.

Table 11. KPIs and informative indicators for soils.

Key performance indicator	Threshold for increased monitoring / modelling	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Atmospheric S deposition and critical load (CL) exceedance risk[9]	S deposition causally related to KMP emissions exceeding CL in > 1% (~20 km^2) of semi-natural upland forest soils in the study area (Figure 4)[10] Action: re-evaluate uncertainties in the regional critical load mapping and re-run the CL model with new data where required	S deposition causally related to KMP emissions exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 200 years (based on projected change in base cations) Action: Pilot application of lime/wood ash, to reduce soil acidity and increase base cation pools to pre-KMP levels, subject to BC MOE[11] approval	S deposition causally related to KMP emissions exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 100 years (based on projected change in base cations) Action: reduction in SO_2 emissions	- Atmospheric S deposition - Magnitude of exchangeable cation pools (Ca, Mg, K, Na) - Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)
Long-term soil	For one plot: a	For one or more	Decrease in the	- Atmospheric S

[9] Even though KMP will become operational during the 6-year period of this plan, risk of CL exceedance remains a *prediction* based on a combination of monitoring data and modeling. Confidence in these predictions will increase through monitoring of atmospheric S deposition and long-term soil acidification.

[10] As described in Section 8.5-2 of the KMP SO_2 Technical Assessment Report (ESSA et al. 2013), undisturbed forest sites on mineral soils comprise 69% of the study area (1991 km^2 of 2,895 km^2).

[11] Information on the feasibility of this mitigation is provided in Appendix G.

Key performance indicator	Threshold for increased monitoring / modelling	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
acidification (rate of change of base cation pool) attributable to S deposition	40% decrease in 5 yrs or a 20% decrease in 10 yrs in exchangeable cation pools for at least one element, and decrease is causally related to KMP emissions Action: extended soil survey and modelling to assess spatial significance of observed base cation loss (i.e., are there wider issues over >1% of the study area?)	plots: a 40% decrease in 5 yrs[12] or a 20% decrease in 10 yrs in exchangeable cation pools for at least one element and in > 1% (~20 km^2) of the area of semi-natural upland forest soils, based on dynamic modelling, and decrease is causally related to KMP emissions Action: pilot application of lime/wood ash to reduce soil acidity and increase base cation pools to pre-KMP levels, subject to MOE approval	magnitude of exchangeable cation pool of ≥ 20% in 10 years, and in > 5% (~100 km^2) of the area of semi-natural upland forest soils, based on modelling, and decrease is causally related to KMP Action: reduction in SO_2 emissions	deposition - Magnitude of exchangeable cation pools (Ca, Mg, K, Na)

Informative indicators[13]	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Magnitude of exchangeable cation pools (Ca, Mg, K, Na)	- Not applicable; supports critical load modeling and calculation of time to depletion of exchangeable cation pools in locations where CL is exceeded	- Atmospheric S deposition and critical load (CL) exceedance risk - Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)
Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)	- Not applicable; supports critical load modeling for locations where CL is exceeded	- Atmospheric S deposition and critical load (CL) exceedance risk - Magnitude of exchangeable cation pools (Ca, Mg, K, Na) relative to the level of exceedance

[12] The first resampling would occur over a 3-year interval (i.e. sampling in 2015 and then 2018) in order to have two data points for the first synthesis. Observed changes during that period would therefore be pro-rated to a 5-year and 10-year rate of change. Sampling will be at 5 year intervals thereafter.

[13] Thresholds for increased monitoring/modelling, or mitigation, are not applicable. These indicators support critical load modeling.

Informative indicators[13]	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Base cation weathering rates	- Not applicable; supports critical load modeling	- Atmospheric S deposition and critical load (CL) exceedance risk

The thresholds for both of the KPIs for soils are related to a proportional areal exceedance of the receptor study domain. In the absence of provincially-established air zone boundaries, the STAR used a study area along the Kitimat valley encompassing the modelled post-KMP 10 kg SO_4^{2-}/ha/yr plume and potentially sensitive terrestrial and aquatic receptor ecosystems. The study domain was defined in agreement with BC MOE, and encompassed 1991 km^2 of forested ecosystems on mineral soil (69% of the study area). The proportional exceedance reported in the STAR was referenced to this domain area. More recently under the Kitimat Airshed Emissions Effects Assessment (ESSA et al. 2014), BC MOE favoured an effects domain based on the area under the modelled 7.5 kg SO_4^{2-}/ha/yr plume. In 2017 the proportional areal exceedance will be evaluated using the original domain area and an effects domain defined by the area under the 7.5 kg SO_4^{2-}/ha/yr plume. Both domains capture near field emission impacts and far field impacts owing to long-range transport of sulphur dioxide emissions.

Figure 4. Semi-natural upland forest soils in the study area. Source: Figure 9.3-2 from ESSA et al. (2013).

5.2 METHODS

Table 12. Overview of methods for calculating the KPI and informative indicator for soils.

Key performance indicators	Method overview
Atmospheric S deposition and critical load (CL) exceedance risk	Re-running the critical load model in 2017
Long-term soil acidification attributable to S deposition	Soil sampling and modelling studies to assess the rate of change in magnitude of exchangeable cation pools (Ca, Mg, K, Na), using all available data sources

Informative indicators	Method overview
Magnitude of exchangeable cation pools (Ca, Mg, K, Na)	Measured from soil samples (if >5% exceedance in study area)
Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)	Deposition monitoring as described in Section 2 and soil samples (if >5% exceedance in study area)
Base cation weathering rates	Soil sampling, laboratory analysis

5.2.1 Atmospheric S deposition and critical load (CL) exceedance risk

The monitoring method for this indicator is described in Section 2. Critical load exceedance (and % of area with CL exceedance) will be re-calculated in 2017, adding weathering rate data from new soil sampling sites, base cation deposition and revised critical limits.

Steps for determining the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

1. Critical load exceedance is expressed in the same unit as sulphur deposition; as such, the magnitude of exceedance is equivalent to the required deposition reduction;
2. Use CALPUFF to explore different emission scenarios for reducing deposition to meet targets (reduced magnitude / areal exceedance);
3. Run the SSMB model to determine the expected magnitude and areal extent of exceedance under revised deposition from Step 2;
4. Iterate Steps 2 and 3 as necessary to achieve the required level of exceedance reduction (see example in Figure 5);
5. Use finalised CALPUFF scenario to inform decisions on facility-based SO_2 emission reduction (options, amounts and timelines presented in Section 8).

6. Implement the chosen methods of facility-based mitigation as per process described in Section 8.
7. Develop revised monitoring and modelling plan for post-mitigation period to determine if the revised emissions and deposition result in the anticipated recovery of soil conditions.

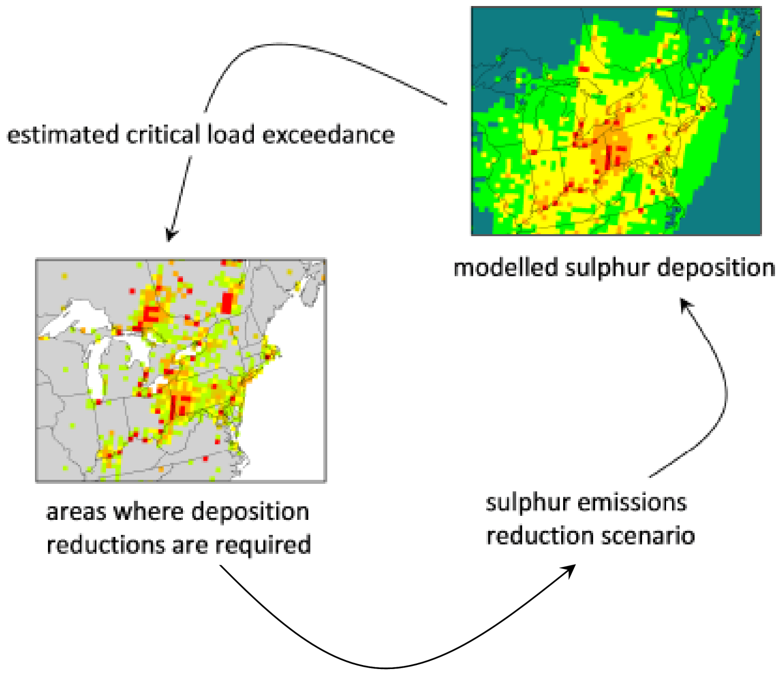

Figure 5. Example showing iterative cycle of critical load exceedance, sulphur emissions reduction scenario, revised modelled deposition based on emissions scenario, and revised (reduced) critical load exceedance

5.2.2 Long-term soil acidification attributable to S deposition

Sampling locations:

- Sites to be determined in consultation with MOE, in long term forest productivity sites; variability of soils will determine the number of samples.
- The Haisla First Nation will be invited to participate in the selection of soil sampling sites.

Sampling duration and frequency, and essential years and times:

- Sampling at 3 plots, every 5 years (with the exception of the first re-sampling interval at 3 years, i.e. 2015, 2018, 2023, 2028, 2033, 2038, etc.).

Sampling methods:

- To be determined in consultation with BC MOE.

How and when monitoring data will be evaluated:

- To be determined in consultation with BC MOE.

Steps for determining the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

1. Use a dynamic model to define a target deposition load, i.e., the deposition required to reach a desired soil chemistry within a specified timeframe;
2. Use CALPUFF to explore different scenarios for reducing deposition to meet the target load;
3. Run the dynamic model to predict timeline of recovery in exchangeable cation pools under revised deposition from Step 2;
4. Iterate Steps 2 and 3 as necessary to stay below the magnitude and timeline thresholds for loss in exchangeable cation pools;
5. Use CALPUFF scenario that emerges from Step 4 to inform facility-based mitigation (options, amounts and timelines presented in Section 8);
6. Implement the chosen methods of facility-based mitigation as per process described in Section 8.
7. Continue monitoring soil plots (5 year internals) to determine if the reduced deposition results in the expected chemical change.

5.2.3 Magnitude of exchangeable cation pools (Ca, Mg, K, Na) compared to S deposition, and time to depletion of these pools

Sampling location, and timing, frequency and duration:

- No additional sampling; we will use the samples obtained for the SO_2 technical assessment, and the supplemental soil collected for determining the base cation weathering rate (as described below).

How and when the analyses will be conducted:

- If exceedance is predicted for >5% of the study area in the analyses to be completed in 2017 (i.e., the receptor-based mitigation threshold is reached for the "atmospheric S deposition and CL exceedance risk" KPI), then archived soil samples (all three layers from the relevant site composite samples) will be analysed for exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium and (Na^{+}) using an unbuffered ammonium chloride extraction (soil samples and extraction solution are shaken for 2 hours and filtered), using flame atomic adsorption spectrometry or inductively coupled plasma optical emission spectrometry.

- The magnitude of exchangeable cation pools will be compared to S deposition to estimate the time to deplete the base cation pool. (I.e., [[TOTAL POOL OF BASE CATIONS] / [ANNUAL EXCEEDANCE]]. For example, a soil with a base cation pool of 1,000 meq/m^2 and an exceedance of 10 meq/m^2/yr would be exhausted in 100 years.)

5.2.4 Base cation weathering rates

Spatial variability in weathering rates of base cations is a source of uncertainty for all critical load calculations. Sites within the study area were identified in the STAR either as: (1) potentially vulnerable (i.e. critical loads may be exceeded); (2) soils not sampled during the SO_2 technical assessment survey that were in areas with low base cation concentration lakes; or (3) regions that were not considered during the initial site selection including glaciofluvial soils. As a result, there are data gaps with respect to the base cation weathering rates for these regions.

Sampling locations:

- Locations associated with: (1) quartz diorite bedrock south of Lakelse Lake, spatially co-located with lakes that had very low base cation concentrations (highest priority); (2) calc-alkaline bedrock near the smelter to support current weathering estimates that were based on extrapolation from other sites (lower priority as this is unlikely to change conclusion of high exceedance; however this is the only region showing exceedance as such site estimates are warranted); (3) orthogneiss metamorphic bedrock in the unsampled southern portion of the study domain consistent with the region receiving high modelled S deposition (southwestern portion of the study area); and (4) surficial geologies not represented in the initial soil sampling.
- Specific sites to be determined in consultation with MOE and Rio Tinto Alcan.

Sampling timing, frequency and duration:

- Sampling will be conducted during the summer of 2015 in a single field campaign. Sampling may also be carried out to take advantage of synergies with water sampling (described in Section 6).

Sampling methods:

- Soil sampling; maximum of 12–18 sites divided equally between the three bedrock categories.
- All field measurements will follow the 2012 protocol described the STAR (with maximum of five soil pits per supplemental study region sampled from three fixed depths: 0 to 10 cm; 15 to 25 cm, and 40 to 50 cm). Samples from each pit will be combined into one composite sample for each depth.
- Laboratory analyses for pH, loss-on-ignition (LOI), particle size (sand, silt and clay), moisture content, bulk density.
- Composite soil samples for each site to be analysed for major oxides, and subset analysed for qualitative mineralogy.

How and when monitoring data will be evaluated:

- Data collected in 2015 will be used to estimate weathering rates for the new sample sites and revise the regional critical load and exceedance maps in 2017. The new weathering rate may be revised to incorporate information on surficial geology if digitally available and if deemed appropriate (e.g., could post-stratify weathering rates based on surficial geology categories).

5.2.5 Summary of Soils actions, 2013-2018

Table 13. Schedule of work on the soils component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Steady state soil modelling	–	Rio Tinto Alcan/MOE/QP collaboration on details of study design for this component. Obtain digitized surficial geology map from BC MOE; overlay with 2012 sampled soil sites. Undertake a sensitivity analysis of STAR predictions under multiple chemical criterion (Bc:Al, Ca:Al, pH, Al).	Develop weight-of-evidence approach for assessing whether change in CL exceedance (if predicted) is causally related to KMP. Conduct additional soil sampling to fill data gaps (QD bedrock type in sensitive lake areas S of Lakelse Lake accessible by road; CA bedrock type near smelter; OG bedrock type in SW part of region; and filling any important gaps for glaciofluvial landforms).	–	Re-do analysis for risk of CL exceedance (and % of area with CL exceedance), adding data from the new sites. Incorporate Bc deposition values from Lakelse monitoring and revised critical limits. Include a sensitivity analysis of multiple chemical criterion. Also calculate for an effects domain defined by the 7.5 kg/ha/yr S deposition isopleth, to compare with using the original study domain area.	Re-analyse archived soils if required based on results of analysis in 2017
Time to depletion of base cation pools (only if triggered by CL exceedance > 5% of study area)	–	–	–	–	Analyze 2012 and new soil to determine base cation exchangeable pools (as an input to the 2017 analysis in the first Soils row).	–
Review critical limit selection: Bc:Al ratio	Obtain digitized vegetation map from VRI	Collaboration with MOE on appropriate critical limit for soils, Bc:Al ratio, by vegetation type (consider use of BEC zones to derive reasonable dominant species boundaries).[14]	–	–	Incorporate any changes in Bc:Al ratio into revised modelling (the 2017 analysis in the first Soils row).	–

[14] A higher Bc:Al ratio results in a lower CL, and a greater chance of exceedance. A sensitivity study could be done on CLs given various ratios.

Topic	2013	2014	2015	2016	2017	2018
Permanent soil plots	–		Establishment of plots in collaboration with BC MOE, initial soil sampling and analysis. Develop weight-of-evidence approach for assessing whether a change in base cation pools in soil samples (if this occurs) is causally related to KMP.–	–	–	Re-sample plots (sampling interval of 5 years thereafter)
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

6.0 Lakes, Streams and Aquatic Biota

6.1 INDICATORS AND THRESHOLDS

The KPI for this receptor is observation-based: water chemistry data will be tracked to determine actual pH change in lakes. Results will reveal the *magnitude* of impact (i.e. how large the pH change is in lakes expected to be affected). The intent and rationale of the sampling and data analysis strategy is described in detail in Appendix H. The first informative indicator for this receptor is prediction-based: measured water chemistry data and measured S deposition data will be used as inputs for updated modeling of critical loads, and expected exceedance of those critical loads. Results will reveal the *extent* of expected impact (i.e. how many lakes might be affected), and will guide where sampling should occur. If the KPI threshold for receptor-based mitigation is reached and receptor-based mitigation is applied but proves ineffective or unfeasible, facility-based mitigation will be implemented.

Table 14. KPI and informative indicators for surface water.

Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Water chemistry – acidification	Observed decrease in pH ≥ 0.30 pH units below mean baseline pH level measured pre-KMP in one or more of the 7 acid-sensitive lakes, and other evidence (see informative indicators and methods) Action: increase frequency of fall sampling in subsequent year, to more accurately estimate mean and variability of pH and other informative indicators during the fall index period. Appropriate sampling frequency to be determined by statistical power analysis.	More intensive sampling confirms a decrease causally related to KMP of ≥ 0.30 pH units below mean baseline pH level pre-KMP and liming is feasible (see Appendices G and I). Action: pilot liming to bring the lake back up to pre-KMP pH, subject to approval by BC MOE/DFO prior to implementation (see Appendix I describing a systematic approach to a pilot liming effort)	More than 2 lakes rated Medium or High (based on relative lake rating; Appendix D) with decrease causally related to KMP of ≥ 0.30 pH units below measured baseline pre-KMP (prior to liming) Action: reduction in SO_2 emissions	- Atmospheric S deposition and CL exceedance risk - Aquatic biota: fish presence / absence per species on sensitive lakes Lake ratings (Appendix D) - Evidence that pH decrease is causally related to KMP SO_2 emissions: ANC, SO_4, DOC (see Section 7)

Informative indicators	Threshold for increased monitoring[15]	Indicators to be jointly considered
Atmospheric S deposition and CL exceedance risk	CL exceeded in more than the 10 acid-sensitive lakes identified in the STAR as having either CL exceedance or predicted to acidify by more than 0.1 pH units (Figure 6)[16]. Action: expand the monitoring to include newly identified lakes with predicted exceedance	- Predicted steady state pH versus current pH (if predicted change > 0.1 pH units then level of concern is higher than if predicted change < 0.1 pH units) - Water chemistry – acidification
Predicted steady state pH versus current pH	Seven lakes with predicted pH change > -0.10 units are included in the set of lakes that are monitored annually each October. Lakes recommended by MOE (MOE-3 and MOE-6, the former sampled in Oct 2013) could be added to this set of annually monitored lakes depending on the outcome of analyses based on sampling in 2013 (MOE-3) and 2014 (MOE-6).	- Surface water model inputs, as described in Section 8.6.3.4 of ESSA et al. (2013)
Estimates of natural variability in pH and other indicators	If the fall index sample is below the pH threshold for any lake, the EEM Program will then obtain four chemistry samples during the fall index period of the following year to better estimate the mean index value and natural variability of pH and other parameters.	- Baseline estimates of natural variability in pH and other indicators during from End Lake (006), Little End Lake (012) and West Lake (023) – see Section 6.2 - These estimates will be used to assess whether observed pH values (and other indicators) are within or outside the range of natural variability
Evidence that pH decrease is causally related to KMP SO_2 emissions	Used in application of all three KPI thresholds	- Trends and levels of SO_2 emissions, SO_4 deposition, N deposition; - Trends and levels of lake ANC, SO_4, NO_3, Cl and DOC in both individual lakes and across all 7 acid-sensitive lakes - See Section 7, also Section 6.2 and Appendix H

[15] Thresholds for mitigation are not applicable. These indicators will provide weight of evidence for assessing the magnitude, extent and causes of lake acidification (Appendix H and Section 7).

[16] The 10 sampled lakes in Figure 6 with either CL exceedance or predicted $\Delta pH > -0.1$ units were the same 10 lakes showing critical exceedance during a sensitivity analysis in which KMP deposition was doubled (STAR, pg. 330). As shown in Table 16, the critical load analysis will be repeated in 2019 using better information. It is unlikely that other sampled lakes will show exceedance under KMP alone, but the 2019 modelling analysis will be completed to confirm or reject this expectation.

Informative indicators	Threshold for increased monitoring[15]	Indicators to be jointly considered
Aquatic biota: fish presence / absence per species on sensitive lakes	Decrease in pH ≥0.30 units confirmed by more intensive sampling in the fall index period Action: resample the fish community in lakes that can be safely accessed for fish sampling	- none
Lake ratings (Appendix D)	Not applicable. Used in thresholds for receptor-based mitigation and source-based mitigation	- none
Episodic pH change	Not applicable	- none
Amphibians	Not applicable	- Atmospheric S deposition

6.2 METHODS

Table 15. Overview of methods for calculating the KPI and informative indicators for surface water.

Key performance indicator	Method overview
Water chemistry - acidification	Water quality sampling to assess trends in ANC, pH, SO_4, base cations. Various analyses to detect water quality trends and whether thresholds have been exceeded (see Section 6.2, Section 7, and Appendix H, especially Table 27).

Informative indicators	Method overview
Atmospheric S deposition and CL exceedance risk	In 2014 re-run the Steady State Water Chemistry (SSWC) and ESSA-DFO models for the 10 lakes sampled in both 2012 and 2013 (to assess fall vs. summer sampling). In 2019 re-run the SSWC and ESSA-DFO models based on water chemistry data for all sampled lakes (those sampled from 2012 to 2018), and then re-run the CL model with the new atmospheric S deposition data
Fish presence / absence per species on sensitive lakes	Fish sampling from standard overnight gill net sets using RIC (1997) nets and small mesh nets
Episodic pH change	Continuous pH measurement in Anderson Creek
Amphibians	Support of community based groups conducting amphibian monitoring

6.2.1 Water chemistry – acidification, and episodic pH change

Ten lakes are sensitive to acidification (Figure 6). This KPI will include water sampling in 7 of these lakes (described below) and laboratory analyses of major anions ([Cl^-], [F^-], [NO_3^-], [$HC0_3^-$]*, [CO_3^{2-}]*, [SO_4^{2-}], [OH^-]*, DOC, Total Alkalinity, Gran ANC), major cations ([Ca^{2+}], [Mg^{2+}], [Na^+], [K^+], [NH_4^+], [H^+], dissolved Al).[17,18] These ions are needed to assess the form, rate and magnitude of changes in lake chemistry, estimate a key parameter (F-factor = Δ base cations / Δ SO_4) for the Steady-State Water Chemistry and ESSA/DFO models, compare deposition-predicted change in SO_4, ANC and pH vs observed change, and confirm QA/QC of water samples by examining charge balance. Ion exchange processes in the watershed can exchange H+ for other cations such as Ca, Mg, Na, K, Al. Dissolved Al is also an indicator of toxicity of water to fish. Lake-specific titration curves will be obtained from the Gran ANC titrations, which will provide the information base for developing lake-specific thresholds for ANC and SO_4.

Sampling will also include field measurements of temperature, dissolved oxygen (e.g., very low oxygen might explain pH shifts), and total dissolved solids.

We will also perform intensive monitoring of Anderson Creek to assess frequency, magnitude and duration of acidic episodes in this stream.

[17] Ions with * are calculated from other measurements.
[18] All of these measurements are important for understanding why pH is changing, which is important for determining if the changes are causally related to KMP (as described in Section 7).

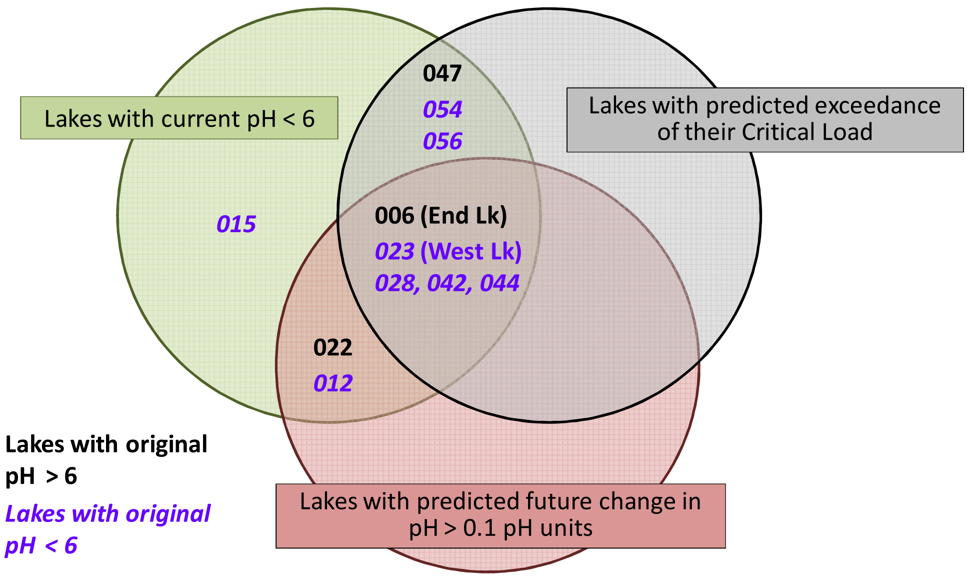

Figure 6. Conceptual diagram of criteria for lake vulnerability. Lake 15 is the only one in the diagram not considered vulnerable, because its original pH was below 6.0 and it is not expected to experience a pH decrease or a critical load exceedance.

Intent and rationale of the sampling strategy: Please see Appendix H for a detailed description.

Sampling locations:

- Essential locations: 7 vulnerable lakes with predicted pH $\Delta > 0.10$. These include: LAK006 (End Lake), LAK023 (West Lake), LAK028, LAK042, LAK044, LAK012, LAK022. Five of these 7 lakes also show critical load exceedance (map provided in Appendix E).[19]
- Two lakes recommended by MOE (MOE-3 and MOE-6[20]).
- Three insensitive lakes to be sampled for chemistry and fish (LAK007, LAK016, LAK034). The insensitive lakes have higher Gran ANC values (1438, 69, 99 µeq/l respectively), do not have exceedance of their CLs, and are not predicted to acidify significantly (predicted ΔpH=0.0, -0.07, 0.03 respectively). In addition to serving as a reference for biological changes, the insensitive lakes will provide a check on model predictions for less acid-sensitive lakes. Fish sampling from the insensitive lakes will occur in 2014.

[19]Three other lakes with CL exceedance are predicted to have a pH change < 0.1 pH units (LAK047, LAK054, LAK056), are low priority for sampling, and are not included in the current field program. LAK047 is a high alpine lake not accessible by fish; LAK054 and LAK056 are naturally acidic, low pH lakes dominated by organic acids (Appendix E).

[20] Site MOE-3 was sampled in October 2013. Site MOE-6 could not be safely sampled in October 2013 due to continuous fog at that high elevation, which prevented helicopter access. . MOE-6 will be sampled in October 2014.

- Lakelse Lake, given its importance and profile in the Valley, even though it is predicted to be insensitive to SO_2 emissions from KMP.
- Cecil Creek (outlet of West Lake) was sampled in 2013, to check if its chemistry mirrors that of West Lake.
- Hydrologic, fish habitat and chemical reconnaissance sampling of Goose Creek, to assess its connectivity to Lake 028, and its sensitivity to acidification.
- Kitimat River (to assure that water supply is not affected by low pH or elevated metals); either upstream of the intake for the Kitimat water treatment plant, or at the intake.
- Anderson Creek (pH measurements to assess frequency and magnitude of acidic episodes).

Sampling timing, frequency and duration:

- The water chemistry of all of these lakes was sampled in October 2013. Chemical data from the sites that were sampled in 2012 (all except the stream sites, MOE-3, and MOE-6) will be used to show the combined effects of inter-year and inter-month variability of CL (August 2012 versus October 2013). Future sampling will occur during the fall when lakes are well mixed, less productive and have greater stability in their chemistry (preferably in October).
- To understand chronic or long term acidification, the 7 acid-sensitive lakes and 3 insensitive lakes will be sampled annually during 2014 to 2018 during the same seasonal timeframe as in 2013 (i.e., fall index period) to track any increase in sulphate and changes in other ions as KMP ramps up (particularly decreases in pH and ANC), and to be able to demonstrate leveling-off to steady state. Minimum emissions are likely to occur in the early part of 2014. Each lake will be considered both independently and also as part of the complete set of 7 acid-sensitive lakes (greater statistical power) with respect to its trends in water chemistry over time.
- In 2014, we will determine if the 2 MOE lakes have CL exceedance or are vulnerable to acidification. If "no", sampling will be discontinued. If "yes", they will be added to the set of vulnerable lakes sampled annually. While the CL has not yet been calculated for MOE-3, the Gran ANC and charge balance alkalinity measurements in the fall of 2013 (168 and 138 µeq/l, respectively) strongly suggest that MOE-3 will not have CL exceedance. See footnote on previous page.
- Anderson Creek: continuous pH sampling, beginning in fall 2014 to get a pre-KMP-ramp up baseline.
- Kitimat River: monthly water quality sampling, beginning after KMP commissioning in 2015 to evaluate any changes in the quality of drinking water

Monitoring protocols and sampling methods:

- The same as for the sampling done in 2012 for these parameters during the SO_2 technical assessment (ESSA et al. 2013).

How and when monitoring data will be evaluated:

- For water quality parameters which show statistically or biologically significant differences between summer 2012 and fall 2013/2014 values, the mean baseline pre-KMP values will be defined as the mean of the fall index samples in 2013 and 2014. For parameters which showed no statistically or biologically significant differences between summer 2012 and fall 2013 samples, the mean baseline pre-KMP values will be defined as the mean of summer 2012, fall 2013 and fall 2014 values.
- During 2014 and 2015 (to be summarized in 2015 EEM report), the program will estimate pre-KMP natural variability in pH and other indicators from End Lake (006), Little End Lake (012) and West Lake (023) through the following steps:
  - A pilot test of continuous pH monitors (calibrated and cross-checked against a field pH meter every two weeks) will record pH every 30 minutes beginning in September 2014 for a period long enough to provide a reliable baseline of variability in pH during the pre-KMP period (except during winter when ice cover prevents access); and
  - Full chemistry samples will be obtained four times during the fall sampling in 2014 to assess baseline natural variability during the index period, and periodically until August 2015, except during winter when ice cover prevents access.
- Estimates of natural variability from 2013-2014 intensive sampling of 3 EEM lakes, plus analyses of Ontario and U.S. lakes (Yan pers. comm; Stoddard et al. 1996) will be used to:
  - Provide estimates of natural variability for all lakes; and
  - Assess statistical power to detect thresholds of interest for both individual lakes and the complete set of 7 acid-sensitive lakes (to be summarized in 2014 EEM report)
- If the fall index sample falls below the pH threshold for any lake, the EEM Program will then obtain more frequent chemistry samples during the same period of the following year to better estimate the mean and variability of pH and other parameters.[21]
- During the period from December to March of each year, monitoring data will be analyzed to assess trends in both individual lakes and in the overall population of 7 acid-sensitive lakes, and in the 3 insensitive lakes, as explained in the following two bullets

[21] It is not feasible to resample a lake more intensively in the fall index period of the same year for two reasons: 1) helicopter time needs to be reserved well in advance; and 2) measurements of pH from the lab (the least variable and best metric for assessing lake pH) will not be immediately available.

- Analyses of trends in individual lakes:
  - Compare fall index sample to pH, ANC and SO_4 thresholds developed from lake-specific titration curves Table 27);
  - Determine if pH thresholds exceeded (KPI), and if reductions in pH are consistent with declines in ANC and increases in SO_4 (informative indicators)
  - Assess whether annual observations are within the range of natural variability, as estimated from 2014-2015 sampling
  - Examine the trend in fall observations for each lake relative to the pre-KMP baseline
  - Determine how individual lakes compare to patterns observed in full set of seven acid-sensitive lakes
- Analyses of trends in the full set of seven acid-sensitive lakes and the set of three insensitive lakes:
  - Examine distribution of estimated changes in pH, ANC and SO_4 (see Figure 17in Appendix H)
  - Conduct paired t-test on pH, ANC and SO_4 to assess mean change in each parameter in each year compared to baseline period, versus thresholds of change for each parameter
  - Conduct trend analyses on the complete set of acid-sensitive lakes to determine overall trends in pH, ANC and SO_4 (see Section 7 and Appendix H)
- The data collected from 2014 to 2018 will be analyzed in early 2019 to:
  - Estimate expected time to steady state for SO_4 based on observed trends in [SO_4] and approximate estimates of water residence time (Table 25).
  - Examine actual Δ SO_4, ANC and pH for all lakes over time relative to steady state predictions of exceedance from SSWC, predicted ANC and pH change at steady state from the ESSA/DFO model, and expected lake [SO_4] from CALPUFF post-KMP predictions of SO_4 deposition / model-based runoff estimates. Apply the approaches described in Section 7 to deduce the most likely causes of acidification at each site.
  - Estimate the F- factor from Δ base cations / Δ SO_4 and compare to the assumed F-factor. The F-factor is an estimate of watershed acid neutralization through cation exchange, where F=0 means that no acidity is neutralized and F=1 means that all acidity is neutralized.

Resampling of STAR lakes:

- Re-sampling of a subset of STAR study lakes may occur if a greater than predicted change in water chemistry of the 10 lakes occurs.

Assess frequency, magnitude and duration of acidic episodes in Anderson Creek, how these change with ramp-up of KMP emissions, how they relate to climatic factors (e.g., snowmelt, storms, first flush after a long dry period in which sulphate gases might have built up in the atmosphere), and how they relate to toxicity thresholds for biota. Anderson Creek provides an indication of acidic episodes in a single stream close to the smelter, but does not provide an assessment of the extent and frequency of acidic episodes across the study area. If acidic episodes are detected in Anderson Creek, then sample other ions in Anderson Creek to determine if these episodes are related to KMP (i.e., SO4-driven) or factors unrelated to KMP (i.e., organic acids, base cation dilution; Bishop et al. 2000). If the episodes in Anderson Creek are shown to be related to KMP, then complete intensive sampling of lake outlets during snowmelt and/or fall storms in Lakes 012, 006 and 023 to compare to baseline intensive sampling in 2014-2015, and determine if the frequency and magnitude of acidic episodes has changed. These 3 EEM lakes will have baseline chemistry information that provide a more thorough - basis for change detection than Anderson Creek.

Steps for determining the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

1. Determine the level of pH and ANC recovery required in each acid-sensitive lake.
2. Look at actual chemical change versus the predicted chemical change in the STAR.
3. Adapt models if required based on observations (e.g., change the F factor).
4. Use the ESSA-DFO model and SSWC sensitivity analyses to determine the target reduction in S deposition necessary to achieve the required pH recovery.
5. Use CALPUFF to explore different scenarios of facility-based mitigation for reducing deposition to meet target (options described in Section 8).
6. Run CALPUFF output through the ESSA-DFO and SSWC models to determine the expected exceedance and pH change with the revised deposition from Step 5.
7. Iterate steps 5 and 6 until a satisfactory reduction in deposition is determined which meets required recovery of pH and ANC identified in Step 1.
8. Implement the chosen methods of facility-based mitigation.
9. Continue monitoring to determine if the revised emissions and deposition result in the anticipated recovery of pH and ANC.

6.2.2 Atmospheric S deposition and critical load (CL) exceedance risk

The monitoring method for this informative indicator is described in Section 2. Critical load exceedance (and % of study area lakes with CL exceedance) will be re-calculated in 2019.

The assumptions in deposition and surface water models affect predictions of magnitude and extent of CL exceedance. Testing these assumptions will require the following inputs:

- Atmospheric S deposition (described in Section 2)
- Base cation deposition (described in Section 5)
- Water chemistry – acidification (described below), specifically major cations ([Ca^{2+}], [Mg^{2+}], [Na^{+}], [K^{+}], [NH_4^{+}], [H^{+}], dissolved Al) and acidic anions ([SO_4^{2-}], [NO_3^{-}], organic anions (commonly represented as[A^{-}]), ANC, DOC)
- ANC is estimated by three different measures to provide redundancy in trend detection total alkalinity, Gran ANC and charge balance alkalinity (Hemond 1990)

Sampling locations:

- As described below, for Water chemistry – acidification

Sampling timing, frequency and duration

- As described in Section 2, for Atmospheric S deposition
- As described in Section 5, for Base cation (Bc) deposition
- As described below, for Water chemistry – acidification
- Kitimat River: monthly water sampling, for two years after KMP startup; then revisit sampling frequency based on observed changes (i.e., does it appear to have reached a steady state?)

Monitoring protocols and sampling methods:

- As described in Section 2, for Atmospheric S deposition
- As described in Section 5, for Base cation deposition
- As described below, for Water chemistry – acidification

How and when monitoring data will be evaluated:

- The acidification models will be re-run in 2019 with the latest input parameters from the sampling described above.
- CLs will be recalculated in 2014 to assess the effects of sampling on different dates (August 2012 compared with October 2013). Lakes are better mixed and less productive in the fall index period, leading to less spatial and temporal variability in lake chemistry (Landers et al. 1987).

6.2.3 Aquatic biota: fish presence / absence per species on sensitive lakes

Sampling locations:

- In safely accessible lakes, which will include 4 vulnerable: LAK023 (West Lake), LAK006 (End Lake), LAK012[22] and LAK044 (Finlay Lake); and the 3 reference lakes: LAK007, LAK016 and LAK034 (map provided in Appendix E).

Sampling timing, frequency and duration:

- The four vulnerable lakes were sampled in the fall of 2013, prior to KMP start-up, coincident with water sampling. In 2013 we also obtained access information for the 3 reference lakes, in preparation for sampling these the following year.
- The 3 reference lakes will be sampled in 2015, to provide a baseline for future measurement.

Monitoring protocols and sampling methods:

- Gill net sampling for fish using RIC (RIC 1997) and small mesh nets (method described in Appendix E). These methods are sufficient to provide reliable information on fish presence / absence and fish age / length distributions. Accurate estimates of fish density are not feasible, as they would require much more gill net time, causing unacceptable levels of fish mortality.

How and when monitoring data will be evaluated:

- Data will be used to clarify for the public the fish communities present in each of the vulnerable lakes that could be safely accessed for fish sampling. Analyses will include:
  - Presence/absence by species, and by age
  - Mean and variance of length and weight for each species by age class
  - Frequency distributions of lengths for each species if sufficient numbers of fish are caught
  - Weight-length plots and equations for each species where sample sizes allow
  - Length at age plots for each species of salmonids where sample sizes permit
  - Simple index of species richness (e.g., number of species caught) and a more complex diversity index (effective species richness as in Jost 2006) if sample sizes permit

6.2.4 Amphibians

Support will be provided to existing local community groups who conduct annual monitoring of amphibians in the Terrace–Kitimat valley. Information generated from amphibian monitoring will be used to help inform the understanding of the health of the environment within the airshed.

[22] LAK006 and LAK012 are connected, and fish can easily move back and forth between them.

6.2.5 Summary of Lakes, Streams and Aquatic Biota actions, 2013-2018

Table 16. Schedule of work on the surface water component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Steady state water modelling	–	Re-run acidification models to calculate CLs, to assess the effects of sampling in Aug (2012) versus Oct (2013).	–	–	–	Organize all data so that acidification models can be re-run in 2019 to calculate CLs and exceedance.
Chemistry: water body sampling	Annual water sampling and laboratory analysis; sample Cecil Creek.	Annual water sampling and laboratory analysis. More intensive sampling of 3 lakes to determine natural variability. Develop weight-of-evidence approach for assessing whether chemical change is causally related to KMP (Section 7 of this document).	Annual water sampling, laboratory analysis, and data evaluation.	Annual water sampling and laboratory analysis, and data evaluation.	Annual water sampling and laboratory analysis, and data evaluation.	Annual water sampling and laboratory analysis, and data evaluation. Review sampling requirements based on outcomes of the data evaluation.
$[SO_4]_0$; F-factor	–	–	–	–	–	Reduce the uncertainties of these factors based on lake chemistry (F) and review of deposition estimates ([SO4]o.
Fish presence / absence sampling	Sampling of 4 vulnerable lakes.	Reconnaissance of habitat and water chemistry in Goose Creek – future sampling TBD based on results.	Sampling of the 3 reference lakes. Resample if lake pH change reaches threshold.	Resample if lake pH change reaches threshold.	Resample if lake pH change reaches threshold.	Resample if lake pH change reaches threshold.
Episodic acidification	–	Initiate study design for snow melt and fall storm episodic acidification in Anderson Creek near KMP (gauged stream). Examine 1997 pH data for Anderson Creek as possible baseline.	Finalize study design.	Implement study.	–	Implement study.
Amphibians	–	Initiate discussion with interested party.	Provide support to existing local community groups who conduct annual amphibian monitoring.	Provide support to existing local community groups who conduct annual amphibian monitoring.	Provide support to existing local community groups who conduct annual amphibian monitoring.	Provide support to existing local community groups who conduct annual amphibian monitoring.
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

7.0 Determination of Causal Relationship to KMP

The KPI thresholds presented in Sections 2 through 6 include the condition that threshold exceedances are causally related to KMP. The process for determining KMP causality is summarized below, by KPI. These steps would be undertaken for a given KPI if the thresholds for increased monitoring or modelling are reached.

Atmospheric SO_2 Concentrations

- Investigate each 1-hour exceedance event by assessing meteorological conditions, and estimates of KMP SO_2 emissions.

Visible Vegetation Injury

- Assess ambient SO_2 concentration data, meteorological conditions, the nature of the injury to foliage (i.e., assess consistency with the known form of impacts to foliage of SO_2) and estimates of KMP SO_2 emissions versus all emissions sources

Atmospheric S Deposition and Critical Load Exceedance Risk for Soils

- Assess the relative likelihood of alternative explanations for critical load exceedances: 1) KMP alone; 2) cumulative effect of non-KMP emission sources including LNG plants and other sources; or 3) cumulative effect of all emission sources including KMP.
- Re-evaluate uncertainties in the mapping and modelling of deposition, critical loads and exceedances

Long-term Soil Acidification Attributable to S deposition

- Conduct an extended soil survey and modelling to assess the spatial significance of observed base cation loss; for example, whether there are there wider issues over >1% of the study area.
- Assess the relative likelihood of alternative explanations for soil acidification: 1) KMP alone; 2) cumulative effect of non-KMP emission sources including LNG plants and other sources; or 3) cumulative effect of all emission sources including KMP.

Atmospheric S Deposition and Critical Load Exceedance Risk for Water

- Assess the relative likelihood of alternative explanations for critical load exceedances: 1) KMP alone; 2) cumulative effect of non-KMP emission sources including LNG plants and other sources; or 3) cumulative effect of all emission sources including KMP.
- Re-evaluate uncertainties in the mapping and modelling of deposition, critical loads and exceedances.

Water Chemistry – Evidentiary Framework for Evaluating the Cause of acidification

Proving causality (i.e., acidification of lakes related to KMP) requires following the cause-effect chain in the source-pathway-receptor diagram (Figure 7), and evaluating multiple lines of evidence for alternative causal pathways. Weight of evidence analyses (Burkhardt-Holm and Scheurer 2007), Marmorek et al. 2011) rely on four types of evidence: 1) a plausible mechanism; 2) exposure to the pollutant; 3) correlation of pollutant exposure and chemical / biological response in space and time; and 4) experimental evidence from the region or other published studies. The pathways and plausible mechanisms of acidification of surface waters are well understood (Marmorek et al. 1989, Baker et al. 1991a), so the focus of the proposed weight of evidence analysis is on exposure, correlation and experimental evidence.

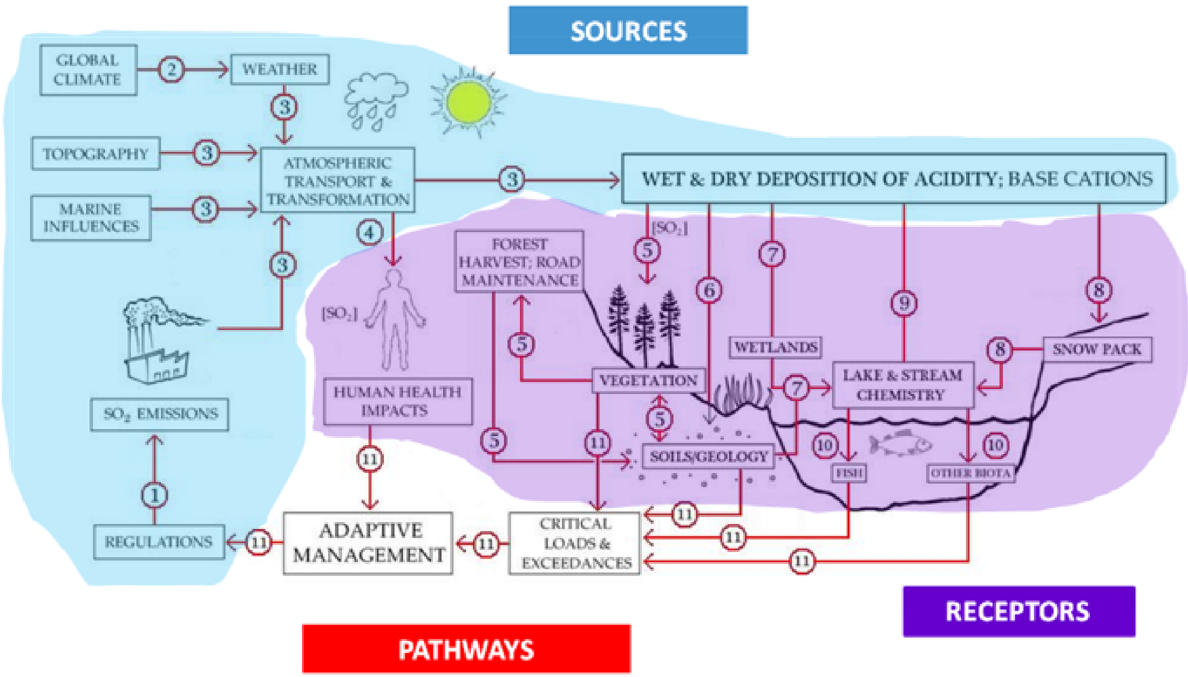

Figure 7. Conceptual (Source-Pathway-Receptor) model of SO_2 emissions in the environment, showing linkages between sources and receptors. Source: Figure 3.1-1 from ESSA et al. 2013.

The evidentiary framework (Table 17) provides a series of questions and tests for various different lines of evidence that then need to be jointly evaluated to draw a conclusion regarding the likelihood that KMP has caused acidification. This conclusion and the associated evidence could be peer reviewed if there are concerns about the data, methods or conclusions. All questions will be reviewed each year, and answered to the degree possible. As the program continues, the statistical power to detect small changes in lake chemistry will increase due to larger sample sizes (Figure 16 in Appendix H). Some questions may not be clearly answerable in the early years of the program due to insufficient sample sizes and limited statistical power. The statistical power analyses discussed in Appendix H will be helpful for defining how many years of data are required to detect changes of interest (e.g., Table 27) with high statistical power.

Table 17. Evidentiary framework for evaluating if acidification has occurred and whether it is or is not related to KMP. SPR = Source-Pathway-Receptor Diagram (Figure 7). The last three columns show answers to the question in column 2.

Links in SPR model	Question	Methods Used to Answer Question [References with examples of these analyses]	Implications of Answers	
			Evidence consistent with KMP as primary cause of acidification	Evidence against KMP as primary cause of acidification
3	Have SO_2 emissions from KMP increased significantly beyond levels in the pre-KMP period, potentially causing increased acidic deposition?	Compare mean daily emissions in pre-KMP period[23] vs. KMP ramp-up period vs. post-KMP steady state period; assess trends. [STAR, Figure 7.4-2, pg. 139; Stoddard et al. 2003]	Yes	No
3	Has SO_4 deposition at Kitimat and Lakelse monitoring stations increased since pre-KMP period in a manner proportional to SO_2 emissions? Has N deposition shown negligible changes? Is deposition of base cations too low to neutralize SO_4 deposition?	Compare monthly and annual SO_4 and N deposition in pre-KMP period vs. KMP ramp-up period vs. post-KMP steady state, and assess trends, for each deposition site. Regress deposition at each site vs. KMP emissions. Also assess trends in [SO_4] in wet deposition (μeq/l/yr) since 2011. [STAR, Figure 7.4-6, pg. 142-143; Stoddard et al. 2003, pg. 21-29]	Yes	No
2, 3	Has background SO_4 deposition (long range sources outside the study area) increased much less than the estimated increase in KMP-related SO_4 deposition, since the pre-KMP period?	Examine trends in SO_4 deposition and [SO_4] in wet deposition from Alaska and other monitoring stations, as reported in the literature. Compare observed change to modelled effect of KMP deposition [ESSA et al. 2014, pg. 259]	Yes	No
3, 8, 9	Has lake [SO_4] increased post-KMP in a manner consistent with predicted increases in deposition of SO_4, and deposition levels inferred from monitoring observations?	Examine distribution of changes in lake [SO_4] across multiple lakes and time trends within individual lakes. Compare trends in [SO_4] to predicted changes in SO_4 deposition with KMP in the STAR, as well as observed SO_4 deposition from Kitimat and Lakelse monitoring stations [Stoddard et al. 1996 [eq 1]; Stoddard et al. 2003, pg. 32-56, Sullivan et al. 1998].	Yes	No
7,9	Do the observed spatial and temporal changes in climate, pH, ANC, dissolved organic carbon (DOC) and sulphate	Examine trends in annual precipitation from meteorological stations, and assess if periods of drought followed by wetter years were correlated with increases in [SO_4] and decreases in ANC [Yan et al.	Yes	No

[23] Further discussion is required to define the pre-KMP period, considering changes in both smelter emissions and other sources (e.g., 2010-2012).

Links in SPR model	Question	Methods Used to Answer Question [References with examples of these analyses]	Implications of Answers	
			Evidence consistent with KMP as primary cause of acidification	Evidence against KMP as primary cause of acidification
	suggest drought-caused oxidation of sulphate stored in wetlands, related to KMP rather than due to climate fluctuations affecting wetland storage of historical S deposition?	1996, Dillon et al. 1996, Stoddard et al. 2003 (pg. 29-30); Laudon et al. 2004]		
8	Has lake ANC decreased post-KMP in a manner consistent with increases in lake [SO_4] and watershed neutralizing abilities (F-factor)?	Examine distribution of changes in lake ANC across multiple lakes and ANC time trends within individual lakes. Compare ANC and SO_4 time trends (e.g., Figure 11, Figure 12 and Figure 13). Examine Δ(Ca + Mg) versus ΔSO_4 to estimate F-factor for each lake, and to understand why ANC has or has not changed. [Section 6.2; Figure 17; Stoddard et al. 1996 [eq 1]; Stoddard et al. 2003 pg. 32-56]	Yes	No
8	Has lake pH decreased post-KMP in a manner consistent with SO_4 increases, ANC decreases, and lake-specific titration curves?	Examine distribution of changes in lake pH across multiple lakes and time trends within individual lakes. Use lake-specific titration curves to assess if SO_4, ANC and pH changes are all consistent with hypothesis of SO_4-driven acidification [Section 6.2; Figure 11, Figure 12 and Figure 13; Figure 17; Stoddard et al. 2003 pg. 32-56]	Yes	No
8	Have lake pH and ANC values decreased beyond identified thresholds (Table 27)?	Use graphs like Figure 17 to assess pH changes across all 7 EEM lakes, and the % of comparisons showing decreases of more than 0.3 pH units, a trigger for more monitoring in Table 14. Examine time trends in pH and ANC using regression analyses for lakes with more intensive monitoring that provide better estimates of natural variation in pH and ANC. [Section 6.2, Appendix H]	Yes	No
2, 3, 7, 8, 9	Are observed changes in Cl, NO_3 and DOC consistent with causes of acidification other than KMP (i.e., sea salt driven episodes, N emissions, organic acidification)?	Examine the percent anion composition of each lake and how it has changed over time [e.g., STAR pages 310 to 314, Marmorek et al. 1988, Marmorek et al. 1989, Baker et al. 1991a, Monteith et al. 2007]	No	Yes

8.0 RIO TINTO ALCAN Mitigation Response for Unacceptable Impacts

Rio Tinto Alcan will implement SO_2 mitigation strategies if the outcomes of monitoring and modeling under the SO_2 EEM Program show adverse impacts related to Rio Tinto Alcan emissions of SO_2 that are considered to be unacceptable. The EEM Program distinguishes two types of mitigations: receptor-based mitigations and facility-based mitigations. The following paragraphs describe examples of each type.

8.1 RECEPTOR-BASED MITIGATION

- If soil critical loads are predicted to be exceeded in >5% of the study area within 200 years, or if exchangeable cation pools will decrease by amounts and within timeframes detailed in Section 5.1, the application of lime and wood ash are options for reducing soil acidity in very localized applications, increasing calcium concentrations in trees, and potentially improving tree growth. Given the wide range of effectiveness of these treatments (summarized in Appendix F), small scale pilot applications would be required as a proof of concept prior to large scale application. The 200 year horizon allows ample of time for a liming/wood ash pilot, and consideration of a shift to facility-based mitigation if the pilot is unsuccessful. Most studies show a response in the soil within 5-10 years.

- If pH in a valued[24] lake declines by more than 0.30 pH units, and the most likely explanation of this pH decline is increased SO_2 emissions from KMP, then if liming is logistically feasible, Rio Tinto Alcan could develop and implement a process to restore the lake pH back to its level in 2012, and reverse the acidification caused by KMP SO_2 emissions. One of the options used to mitigate acidic conditions in surface water is the addition of alkaline materials like limestone (calcium carbonate). Depending on lake access, safety and other environmental considerations, liming could be done on the whole lake, its running water or on its watershed using a boat, truck or helicopter (Olem 1990). A summary of the state of knowledge regarding liming of lakes is provided in Appendix G. Liming would only be applied for up to two lakes; if more than 2 lakes show pH declines greater than 0.30 units and related to KMP, Rio Tinto Alcan would implement facility-based mitigation[25].

[24] Refer to Appendix D for information on the method and results for rating the vulnerable lakes.
[25] Refer to Section 6.1 for the thresholds for receptor-based mitigation.

8.2 FACILITY-BASED MITIGATION

Sections 3.1, 4.1, 5.1 and 6.1 describe (respectively) the health, vegetation, soil and surface water thresholds for facility-based mitigation. Facility-based mitigation will be a response to demonstrated unacceptable impacts caused by SO_2 emissions resulting from KMP future operations. Facility-based mitigation will reduce SO_2 emissions from the smelting operation by a sufficient level to address the demonstrated unacceptable impact, and may be episodic or permanent depending on the persistence of the threshold exceedance. The methodology for reducing SO_2 emissions will be an Rio Tinto Alcan business based decision that will factor in consideration of the nature of the impacts, feasibility and sustainability of alternative mitigation methods, and market place conditions. Some of the options that Rio Tinto Alcan will consider for reducing SO_2 emissions are briefly described below, followed by Table 18 which presents the range of SO2 reduction in t/day that could be achieved, and the implementation timeline.

a) Procuring lower sulphur content coke

   The coke blend used for anode manufacturing can be adjusted to lower the overall sulphur content in the anode. The magnitude of the sulphur content reductions will be determined based on market place conditions and accessibility to anode grade cokes with lower sulphur content.

b) Reducing the amount of calcined coke produced on site

   Increased quantities of calcined coke can be procured to reduce the amount of coke calcining onsite. The feasibility of this option will be based on market place conditions for anode grade calcined coke.

c) Importing anodes

   Baked anodes can be imported to Kitimat to either reduce or stop coke calcining or anode baking operations. This option would be reviewed for feasibility based on market place access to baked anodes and transportation costs.

d) Scrubber on Coke Calciner

   Implementing a scrubber on the coke calciner is possible. A decision to implement scrubbing on the coke calciner will be based on a business review of a scrubbing option compared to costs, and the accessibility of either lower sulphur content cokes or increased quantities of calcined coke. The assessment will also consider the environmental impact assessment of this mitigation measure, including waste generation, energy consumption, GHG emissions, the operating risks of the scrubber and the acceptability to stakeholders of the selected type of feasible scrubbing.

e) Scrubbing on one or both gas treatment centres

The option of implementing scrubbing on one or both gas treatment centres will be based on a business case review of the options to reduce SO_2 emissions from the Kiitmat smelter. The review will consider the construction and operating costs of the scrubber in comparison to the feasibility assessment of the other options to reduce SO_2 loadings from smelting operations. The assessment will also consider the environmental impact assessment of this mitigation measure, including waste generation, water release, energy consumption, GHG emissions, the operating risks of the scrubber and the acceptability to stakeholders of the selected type of feasible scrubbing.

Table 18. SO_2 reduction options and associated timeline for reduction[26].

Reduction option	potential range of reduction		Implementation timeline
	minimum t/day	maximum t/day	
Procuring lower sulphur content coke	1	15	3 to 6 months
Reducing the amount of calcined coke produced on site	1	8	Short-term curtailment: 1 day to 2 weeks Long-term curtailment: 6 months
Importing anodes with lower sulfur content	1	20	6 to 18 months
Scrubber on Coke Calciner	7	NA	5 - 6 years : a) Feasibility study: 1 year b) Permitting: 1 years c) Engineering, Procurement, Construction: 2 - 3 Years d) Commissioning: 1 years
Scrubber on 1 GTC	14	NA	7-8 years : a) Feasibility study: 1 years b) Permitting: 2-3 years c) Engineering, Procurement, Construction: 3 years d) Commissioning: 1 years
Scrubbers on 2 GTC	29	NA	

[26] One or more of these reduction options would only be implemented if there is:

- a confirmed environmental impact related to KMP SO_2 emissions,
- an EEM KPI source-based mitigation trigger is reached, and
- the needed amount of SO_2 reduction has been determined through the methods described in sections 3-6 of this document.

These options are not binding, as the efficacy and availability of some options may vary with time and other options may become available in the future

9.0 Annual Reporting, and Comprehensive Review in 2019

9.1 ANNUAL REPORTING AND CONSULTATION

SO_2 EEM reporting will occur on an annual basis. These annual reports will contain a concise summary of activities and results from the year, and plans for the subsequent field program based on the results from the previous field season. Information on aluminum production and SO_2 for the past year will also be included, to provide context for results interpretation. The annual reports will be written for a non-technical audience and intended for public distribution. Annual report preparation will begin early in the next calendar year, with the intention of publication by March 31st. Details of the results from each year will be documented in technical memoranda, allowing access to the technical details for the ECC, KPAC, and anyone else who is interested. The Haisla First Nation will be invited to participate in detailed annual program reviews, study designs and evolutions of the EEM program.

Each year of the EEM program, a meeting will be called to review the annual EEM program report and during the course of the meeting develop an interpretation of the EEM data integrated across the four lines of evidence (surface waters, vegetation, soils, and human health).

Annual Kitimat Public Advisory Committee (KPAC) meetings will be held in each spring to review EEM results and report out on the findings from the previous year, and discuss actions planned for that year.

9.2 COMPREHENSIVE REVIEW IN 2019

A comprehensive review will be conducted in 2019, examining what has occurred under the SO_2 EEM Plan from 2013 to 2018. A report synthesizing the results of this review will be prepared by October 31, 2019, which will:

- Summarize what has been learned, and what question have been answered,
- Describe which if any of the KPI thresholds have been reached, and if so, what actions were taken,
- Describe any modifications to KPIs, methods or thresholds that have been made based on annual results to date, and why,
- Look across the data sets of the four lines of evidence to develop an holistic understanding of KMP SO2 effects on the environment and human health,
- Recommend changes if/as needed to: the suite of KPIs to be continued post-2018, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes, and
- Recommend a date for the next comprehensive review.

10.0 References

Baker, L.A., P. R. Kaufmann, A.T. Herlihy, J.M. Eilers. 1991a. Current Status of Acid Base Chemistry (Rep 9), NAPAP State of Science and Technology, NAPAP, Washington, DC. 383 pp.

Baker, L.A. Alan T. Herlihy, Philip R. Kaufmann, Joseph M. Eilers. 1991b. Acidic Lakes and Streams in the United States: The Role of Acidic Deposition. Science, Vol. 252, No. 5009, pp. 1151-1154.

Benke, A.C., A.D. Huryn, L.A. Smock and J.B. Wallace. 1999. Length-mass relationships for freshwater macroinvertebrates in North America with particular reference to the southeastern United States. Journal of the North American Benthological Society, 18: 308-343.

Bishop, K.H, H.Laudon, S. Kohler. 2000. Separating the natural and anthropogenic components of spring flood pH decline: A method for areas that are not chronically acidified. Water Resources Research 36(7): 1873-1884.

Brown, G.W., D. Roderick, A. Nastri. 1991. Dry Scrubber Reduces SO_2 in Calciner Flue Gas. Oil & Gas Journal, 89 (7). ABI/INFORM Global p. 41.

Burkhardt-Holm, P. and K. Scheurer. 2007. Application of the weight-of-evidence approach to assess the decline of brown trout (Salmo trutta) in Swiss Rivers. Aquatic Sciences. 69: 51-70.

Downie, A.J. 2005. Drinking Water Source Quality Monitoring 2002-03 – Parasite Sampling in Northwest Coastal Communities: Prince Rupert, Terrace and Kitimat. BC Ministry o f Environment. 41 pp.

Dillon, P.J., L.A. Molot, and M. Futter. 1997. The effect of El Nino-related drought on the recovery of acidified lakes. Environmental Monitoring and Assessment 46:105-111.

Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. Acid Rain Revisited: advances in scientific understanding since the passage of the 1970 and 1990 Clean Air Act Amendments. Hubbard Brook Research Foundation. Science Links™ Publication, Vol. 1, No.1. Available at:http://www.hubbardbrook.org/6-12_education/Glossary/AcidRain.pdf. Accessed June 14, 2013.

Eilers, J.M, G.J. Lien and R.G. Berg. 1984. Aquatic Organisimgs in Acidic Environments: A Literature Review. Department of Natural Resources Technical Bulletin No. 150. Madison, WI, 20 pp.

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants, and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia

Permit for the Kitimat Modernization Project. Volume 2: Final Technical Report. Prepared for Rio Tinto Alcan, Kitimat, B.C. 450 pp.

ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2014. Kitimat Airshed Emissions Effects Assessment. Report prepared for BC Ministry of Environment, Smithers, BC. 205 pp. + appendices.

Hemond, H.F. 1990. Acid Neutralizing Capacity, Alkalinity, and Acid-Base Status of Natural Waters Containing Organic Acids. Environ. Sci. Technol. 24:1486-1489.

Jost, L. 2006. Entropy and diversity. Oikos, 113(2), 363-375.

Landers, D.H., J. M. Eilers, D.F. Brakke, W.S. Overton, P.E. Keliar, M.E. Silverstein, R.D. Schonbrod, R.E. Crowe, R.A. Linthurst, J.M. Omernik, S.A. Teague, and E.P. Meier. 1987. Characteristics of Lakes in the Western United States. Volume I. Population Descriptions and Physico-Chemical Relationships. EPA/600/3-86/054a. U.S. Environmental Protection Agency, Washington, DC. 176pp.

Laudon, H., P.J. Dillon, M.C. Eimers, R.G. Semkin, and D.S. Jeffries. 2004. Climate-induced episodic acidification of streams in central Ontario. Environ. Sci. Technol. 38:6009-6015.Laurence, J. A. 2010. A Review of the Vegetation Monitoring and Assessment Program in the Vicinity of the Rio Tinto Alcan British Columbia Operations at Kitimat, British Columbia. Report to Rio Tinto Alcan dated May 16, 2010.

Lester, N. P., P. E. Baily, and W. A. Hubert. 2009. Coldwater fish in small standing waters. Pages 85-96 in Standard Methods for Sampling North American Freshwater Fish. S. Bonar, W. Hubert, and D. Willis (eds.). American Fisheries Society, Bethesda, Maryland.

Marmorek, D.R., D.P. Bernard, M.L. Jones, L.P. Rattie, and T.J. Sullivan. 1988. The effects of mineral acid deposition on concentrations of dissolved organic acids in surface waters. Report prepared by ESSA Environmental and Social Systems Analysts Ltd. and Northrop Services Inc. for the US Environmental Protection Agency, Corvallis, Oregon. 110 pp.

Marmorek, D.R., D.P. Bernard, C.H.R. Wedeles, G.D. Sutherland, J.A. Malanchuk, and W.E. Fallon. 1989. A protocol for determining lake acidification pathways. Water Air and Soil Poll. 44: 235-257.

Marmorek, D.R., D. Pickard, A. Hall, K. Bryan, L. Martell, C. Alexander, K. Wieckowski, L. Greig and C.Schwarz. 2011. Fraser River sockeye salmon: data synthesis and cumulative impacts. Technical Report 6. The Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River. 363 pp.

Monteith, D.T., J.L. Stoddard, C.D. Evans, H.A. de Wit, M. Forsius, T. Hogasen, A. Wilander, B.L. Skjelkvale, D.S. Jeffries, J. Vuorenmaa, B. Keller, J. Kopacek, and J. Vesely. 2007. Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. Nature 450:537-540.Olem, H. 1990. Liming Acidic Surface Waters, Issue 15 in NAPAP Acidic deposition, state of science and technology report: Aquatic processes and effects. Olem Associates. 149 pp. + Appendices.

RIC. 1997. Fish Collection Methods and Standards. Prepared by the B.C. Ministry of Environment, Lands and Parks, Fish Inventory Unit for the Aquatic Ecosystems Task Force, Resources Inventory Committee (RIC).

Smock, L. A. 1980. Relationship between body size and biomass of aquatic insects. *Freshwater Biology* 10: 375-383.

Stoddard, J. L., A. D. Newell, N. S. Urquhart, and D. Kugler. 1996. The TIME project design: II. Detection of regional acidification trends. Water Resources Research 32:2529-2538.

Stoddard, J.L., J.S. Kahl, F.A. Deviney, D.R. DeWalle, C.T. Driscoll, A.T. Herlihy, J.H. Kellogg, P.S. Murdoch, J.R. Webb, and K.E. Webster. 2003. Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990. EPA 620/R-03/001. US Environmental Protection Agency, Office of Research and Development. National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC 27711. 92 pp.

Strømmen, S.O. , E. Bjørnstad, G. Wedde. 2000. ALSTOM POWER NORWAY. SO_2 Emission Control in the Aluminium Industry. TMS 2000.

Sullivan, T.J., J.M. Eilers, M.R. Church, D.J. Blick, K.N. Eshleman, D.H. Landers, and M.S. DeHaan. 1988. Atmospheric wet sulphate deposition and lakewater chemistry. Nature 331:607-609.

Yan, N.D., W. Keller, N.M. Scully, D.R.S. Lean, and P.J. Dillon. 1996. Increased UV-B penetration in a lake owing to drought-induced acidification. Nature 381:141-143.

Appendix A: Questions the SO_2 EEM Program Will Answer

Questions that arose during the SO_2 technical assessment – and which are important to answer in the SO_2 EEM Program (as explained in Section 1.2) – are summarized in Figure 8. While most of the questions pertain directly to the receptors, three of the questions pertain to impact pathways – and as such, the answers may affect the predicted impact categories for one or more of the receptors. The questions are listed in greater detail in Table 19. At least two hypotheses representing alternative outcomes are provided for each question (where applicable). In addition to answering these assessment questions, the SO_2 EEM Program will also answer the question, *will SO_2 emissions from KMP have unacceptable impacts on any these four receptors?* Table 20 matches the EEM indicators to these questions.

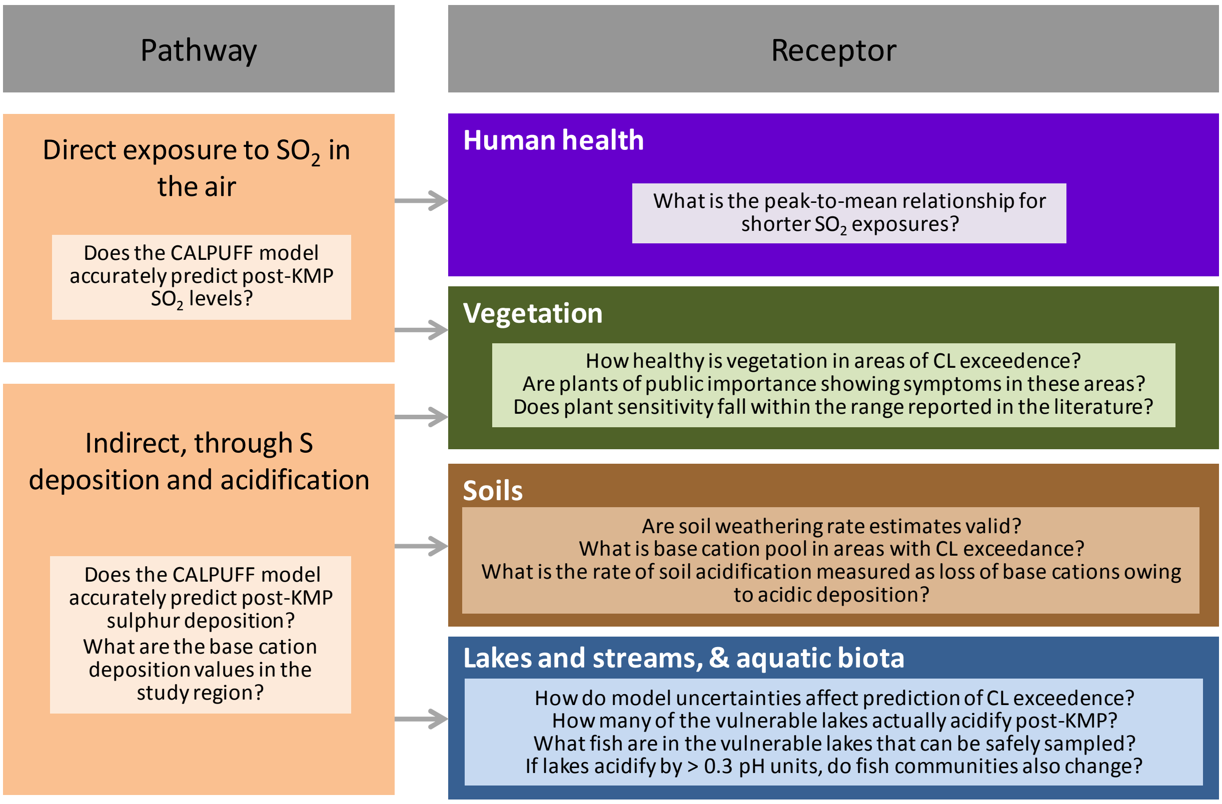

Figure 8. Summary of the questions that the KPIs and informative indicators in the SO_2 EEM Program will answer, by pathway and receptor.

Table 19. Questions and hypotheses that will be addressed in the SO_2 EEM Program.

Pathway or Receptor	Question	Hypotheses
Atmospheric Concentrations	**A1.** Does CALPUFF accurately represent post-KMP SO_2 air concentrations? *Affects predictions for all receptors, either directly (i.e., sulphur exposure impacts) or indirectly (i.e., acidification impacts).*	H_1. CALPUFF model predictions fall within an acceptable range when compared to actual SO_2 concentration data. H_2. CALPUFF model predictions fall outside an acceptable range when compared to actual SO_2 concentration data.
Atmospheric Deposition	**D1.** Does the CALPUFF model accurately predict post-KMP total sulphur deposition? *Affects predictions of acidification for soil, lakes and streams.*	H_1. Total sulphur deposition measurements show an acceptable level of agreement with CALPUFF predictions. H_2. Total sulphur deposition measurements are lower than CALPUFF predictions (i.e., CALPUFF was conservative). H_3. Total sulphur deposition measurements are higher than CALPUFF predictions.
	D2. What are the base cation deposition values in the study region?	H_1. Measurements of base cation deposition result in reduced estimates of magnitude or extent of exceedance of soil and water critical loads (or no change in predictions). H_2. Measurements of base cation deposition do not result in reduced estimates of exceedance of soil or water critical loads.
Human Health	**HH1.** How conservative is the CALPUFF model in predictions of SO_2 levels?	H_1. Model predictions are conservative or similar to actual post-KMP conditions in residential areas. H_2. Pre-KMP model predictions underestimate SO_2 levels in residential areas (i.e., greater SO_2 concentrations post-KMP).
	HH2. What is the peak-to-mean relationship for shorter duration exposures?	H_1. The peak-to-mean ratios observed post-KMP are equal to or less than that produced by the model. H_2. The observed peak-to-mean ratios post-KMP are greater than what is modelled.
Vegetation	**V1.** Validation of the dispersion model – are we looking in the right place?	H_1. Post-KMP passive and continuous monitoring measurements show a similar SO_2 concentration distribution to that predicted by the model. H_2. Post-KMP passive and continuous monitoring measurements show a different SO_2 concentration distribution to that predicted by the model.

Pathway or Receptor	Question	Hypotheses
	V2. How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?	No hypotheses to test; answering the question requires monitoring for damage in areas of highest predicted critical load exceedance.
	V3. Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?	H_1. Negligible or no effects. H_2. Indirect effects on plants via changes in soil base cations and Al are moderate. H_3. Indirect effects on plants via changes in soil base cations and Al are significant.
	V4. Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?	H_1. Yes, the scientific literature accounts for the responses of the most sensitive plants. H_2. No, symptoms indicate that plants at Kitimat may be more sensitive than those reported in the literature.
Soils	**S1.** Are estimates of average weathering rates by bedrock type valid for vulnerable areas (e.g., where lakes have low base cations)?	H_1. Estimates of soil weathering rates used in this assessment are applicable to vulnerable areas such as lakes with low base cations. H_2. Estimates of soil weathering rates used in this assessment are too high for the most vulnerable areas, resulting in underestimates of exceedance of soil critical loads.
	S2. What is the current buffering capacity (base cation pool) of the soils in exceeded areas?	H_1. The current buffering capacity of soils is large and under post-KMP deposition it will take many decades to be depleted. H_2. The current buffering capacity of soils is small and under post KMP deposition it will take only a few years to be depleted.
	S3. What is the rate of soil acidification measured as loss of base cations (or increase in protons) owing to acidic deposition?	H_1. Measurements of actual base cation loss indicate the magnitude and extent of soil acidification will be as predicted, and will take many decades or more. . H_2. Measurements of actual base cation loss indicate the magnitude or extent of soil acidification will occur within only a few years or a few decades.

Pathway or Receptor	Question	Hypotheses
Lakes and Streams and Aquatic Biota	**W1.** How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post- KMP?	H_1. Predicted extent and magnitude of exceedances are reasonable, or are overestimates. H_2. Predicted extent and/or magnitude of exceedances are underestimates.
	W2. How many of the 7 lakes with predicted pH change >0.1 actually acidify under KMP, and to what extent? Are additional lakes suggested by MOE (MOE-3 and MOE-6) likely to receive deposition in excess of critical load? What is the water chemistry of the insensitive lakes?	H_1. Changes in water chemistry post-KMP (acidification) are similar to SSWC and modified ESSA/DFO predictions. H_2. Changes in water chemistry post-KMP are less than predicted. H_3. Changes in water chemistry post-KMP are greater than predicted.
	W3. What species, age classes, and size of fish are present in the potentially vulnerable lakes that can be safely accessed for fish sampling?	Establish baseline conditions of fish communities prior to implementation of KMP.
	W4. If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?	H_1. No loss of any fish species. H_2. Loss of some fish species.

The following paragraphs summarize why each of these questions is important to answer in the SO_2 EEM Program.

A1.* *Does the CALPUFF model accurately predict post-KMP SO_2 air concentrations?

Modelled estimates of post-KMP concentrations of SO_2 are used to assess effects of sulphur on human health and vegetation, and also drive deposition estimates (explained under **D1**). The accuracy of the SO_2 concentrations predicted in the CALPUFF model therefore affects the accuracy of the assessment for all of the receptors. If CALPUFF underestimated post-KMP SO_2 concentrations, impacts on receptors may be greater than predicted; alternatively if CALPUFF overestimated SO_2 concentrations, impacts may be less than predicted. Conducting updated CALPUFF modelling using post-KMP estimates of SO_2 concentration will answer questions regarding SO_2 exposure impacts, and provide a reliable, empirically-calibrated tool which can be used to explore mitigation options.

D1. *Does the CALPUFF model accurately predict post-KMP total sulphur deposition?*

Modelled estimates of post-KMP sulphur deposition are used to predict critical load exceedances for soils and lakes and streams. If CALPUFF underestimated post-KMP SO_2 concentrations, impacts on receptors may be greater than predicted; and if CALPUFF overestimated these concentrations then impacts may be less than predicted. Conducting updated CALPUFF modelling using post-KMP estimates of sulphur deposition will answer questions regarding exceedance of critical loads and acidification impacts, and provide a reliable, empirically-calibrated tool which can be used to explore mitigation options.

D2. *What are the base cation deposition values in the study region?*

Base cation deposition in the study region is not known. This is important for the critical load analyses (and more so for soil than water analysis, described further under **W1**). In the absence of any reliable estimates, the soil critical load analyses for the technical assessment conservatively assumed that base cation deposition was zero, meaning that any base cation deposition will increase soil critical loads and may potentially reduce estimates of exceedance.

HH1. *How conservative is the CALPUFF model in predictions of SO_2 levels?*

Explained under **A1.**

HH2. *What is the peak-to-mean relationship for shorter duration exposures?*

Respiratory responses in individuals with restrictive airway diseases are most closely linked to short-term peaks of SO_2 exposure. The shortest time period over which monitoring data are available is a 1-hour average. Therefore the relationship between 1-hour averages and these shorter-term peaks must be determined in order to accurately predict the risk. (This will be used to evaluate how close SO_2 measurements fit with air modelling used to predict air restriction events, but will not itself be an indicator.)

V1. *Validation of the dispersion model – are we looking in the right place?*

Relates to **A1.** Conclusions about impacts (predicted to be low (green)) on vegetation from direct exposure to SO_2 based on evidence of vegetation damage may be underestimated if damage surveys are not done in the areas where highest concentrations of SO_2 are expected.

V2. *How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?*

Indirect impacts on vegetation from soil acidification are predicted to be low (green). Sensitivity analyses of soil critical loads based on *minimum* estimates of mineral weathering rates (as opposed to *average* weathering rates) suggest that a few areas in quartz diorite bedrock south of Lakelse Lake could exceed the soil critical load post-KMP (further explained under **S1**). Extension of existing vegetation surveys to these areas would help to detect any indirect soil-mediated effects on vegetation (i.e., symptoms of base cation depletion or aluminum toxicity in the rooting zone of plants).

***V3.** Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?*

As for **V2**, but applicable to exceedances elsewhere than just south of Lakelse Lake, and explicitly focusing on plants of particular value to stakeholders.

***V4.** Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?*

If the only plants showing symptoms of direct impacts are found in locations with SO_2 concentrations *greater than* literature thresholds for damage (i.e., one would expect plants to show damage based on literature thresholds), then all plants fall within the range of variation in the literature. If however plants show symptoms of direct impacts in locations with SO_2 concentrations *lower than* literature thresholds, then it suggests that some plants may have a greater sensitivity than those plants used in dose-response experiments and other studies to derive damage thresholds in the literature.

***S1.** Are estimates of average weathering rates by bedrock type valid for vulnerable areas (e.g., where lakes have low base cations)?*

This question about weathering rates for base cations arises for all critical load studies. Critical loads for soils were estimated during the technical assessment using a limited number (four to six) soil pits within each bedrock category, therefore there are areas in the study region where weathering rates are underestimated. Answering this question is most important for two bedrock types in an area south of Lakelse Lake where exceedance is not predicted using estimates of average weathering rates, but is predicted using estimates of minimum weathering rates. This work would likely not change the predictions of high exceedance for a very small area near the smelter, or the overall impact category predicted to be moderate (yellow), as the potentially affected area is a very small percentage of the study region. It would however increase confidence in the assessment, and provide more informative estimates of exceedance risks, including how long it would take for soils to reach various thresholds (described under **S2**).

***S2.** What is the current buffering capacity (base cation pool) of the soils in exceeded areas, and when would this base cation reservoir be used up?*

The mass balance models used to determine whether critical loads will be exceeded do not provide information on *when* exceedance will occur. Estimating how long it will take to use up the base cation reservoir will provide a temporal element to the interpretation of the impacts of exceedances.

***S3.** What is the rate of soil acidification measured as loss of base cations owing to acidic deposition?*

There are assumptions in the deposition and soil models used to derive impact predictions (questions **S1** and **S2**). Monitoring soils that are potentially susceptible to acidification will help to understand the time to depletion of base cation pools in regions of exceedance under potential future acidification.

***W1.** How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post-KMP?*

Predictions of sulphur deposition affect estimates of both critical loads and exceedances, so the answer to **D1** is important. Similar to the soil critical loads analyses, the water critical loads analyses in the technical assessment also assumed that deposition of base cations was zero, *but* implicitly capture any base cation deposition as part of the measured base cation concentration in the lake, and ascribe all of this to mineral weathering in the calculation of original pre-industrial base cation concentrations ($[BC^*]_0$). Changes in base cation deposition (question **D2**) could affect the estimates of critical loads and exceedance for acid-sensitive lakes, but are unlikely to affect the extent of exceedance because such a high proportion of lakes and lake area in the study area is insensitive to acidification. After several years of monitoring water chemistry, if $[SO_4^*]$ has changed, it will be easy to empirically estimate an F-factor for each lake ($\Delta[BC^*] / \Delta[SO_4^*]$).

***W2.** How many of the seven potentially vulnerable lakes with predicted pH change > 0.1 actually acidify under KMP, and to what extent? Are additional lakes suggested by MOE (MOE-3 and MOE-6) likely to receive deposition in excess of critical load? What is the chemical status of insensitive lakes?*

There are various assumptions in the deposition and surface water models used to derive impact predictions. Existing information and sensitivity analyses (described under **W1**) provides a high level of confidence in the potential extent of acidification (low to moderate), but less confidence in the magnitude of acidification (i.e., observed versus predicted exceedance and pH change). Monitoring lakes that are potentially susceptible to acidification will help to increase confidence in model predictions. Monitoring results could reduce the impact category from moderate (yellow) to low (green), but are unlikely to increase the impact category beyond moderate (yellow).

***W3.** What is the current status of the fish communities in the subset of potentially vulnerable lakes that can be safely accessed for fish sampling?*

This is important because the acceptability of impacts of possible acidification in the acid-sensitive lakes will depend on the fish communities present in those lakes, and how important these fish communities are to stakeholders. Prior to the EEM Program there was only limited empirical information on fish composition for two of the 10 lakes being considered in the EEM plan (West Lake and End Lake). Having a baseline is essential for evaluating potential future changes (**W4**), where such a baseline can be safely established given access issues. Sampling in the fall of 2013 provided information on fish communities in four of the seven EEM lakes that could be safely accessed for fish sampling. The results of these field surveys (and other available information on fish populations) are summarized in row 4 of Table 22 in Appendix D of this document.

W4. *If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?*

This follows from **W2** and **W3**. If some of the lakes which can be safely sampled for fish show pH declines sufficient to potentially affect fish (i.e., a pH decline >0.30 units, evaluated under **W2**), then it is appropriate to resurvey the fish composition of the sensitive and insensitive lakes in the future (to determine whether changes were related to acidification or other factors). This would provide greater confidence in the actual *magnitude* of impacts in susceptible surface waters, but is unlikely to affect estimates of the *extent* of impacts, as explained under **W1**. Therefore the impact category is not expected to change.

Table 20. Alignment of key performance and informative indicators with the questions that the SO_2 EEM Program will answer.

		Key performance indicators and informative indicators															
Pathway or Receptor	Question (those with bold numbers were identified in the STAR)	SO_2 concentration	S deposition	Base cation deposition	Predicted annual # of SO2-associated respiratory responses	**Visible vegetation injury caused by SO_2**	S content in Hemlock needles	**Atmospheric S deposition & CL exceedance in soil**	**Long-term soil acidification attributable to S deposition**	Magnitude of base cation pools	Time to depletion of exchangeable cation pools	Base cation weathering rate	Atmospheric S deposition & CL exceedance in water	**Water chemistry - acidification**	Fish presence / absence per specie on sensitive lakes	Episodic pH change on Anderson creek	Amphibians
Atmosphere	**A1.** Does CALPUFF accurately represent post-KMP SO_2 air concentrations?	■					■										
	D1. Does the CALPUFF model accurately predict post-KMP total sulphur deposition?	■	■														
	D2. What are the base cation deposition values in the study region?		■	■													
Human Health	**HH1.** How conservative is the CALPUFF model in predictions of SO_2 levels?	■															
	HH2. What is the peak-to-mean relationship for shorter duration exposures?	■															
	Is the increased SO_2 having an impact on population health?				■												
Vegetation	**V1.** Validation of the dispersion model – are we looking in the right place?	■				■	■										
	V2. How healthy is vegetation in sites with predicted exceedance of CLs of soil and/or lakes south of Lakelse Lake?					■											
	V3. Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?					■											
	V4. Do plants at Kitimat with unknown sensitivity to acidic deposition fall within the range of variation in the literature?					■											
	Is the increased SO_2 having an impact on vegetation?					■											
Soils	**S1.** Are estimates of weathering rates by bedrock type valid for vulnerable areas (e.g. where lakes have low base cations)?											■					

		Key performance indicators and informative indicators															
Pathway or Receptor	Question (those with bold numbers were identified in the STAR)	SO_2 concentration	S deposition	Base cation deposition	Predicted annual # of SO2-associated respiratory responses	**Visible vegetation injury caused by SO_2**	S content in Hemlock needles	**Atmospheric S deposition & CL exceedance in soil**	**Long-term soil acidification attributable to S deposition**	Magnitude of base cation pools	Time to depletion of exchangeable cation pools	Base cation weathering rate	Atmospheric S deposition & CL exceedance in water	**Water chemistry - acidification**	Fish presence / absence per specie on sensitive lakes	Episodic pH change on Anderson creek	Amphibians
	S2. What is the current buffering capacity (base cation pool) of the soils in exceeded areas?									■	■						
	S3. What is the rate of soil acidification, measured as loss of base cations owing to acidic deposition?			■					■	■	■						
	Is the increased SO_2 having an impact on soils?							■	■	■	■						
Lakes and Streams and Aquatic Biota	**W1.** How do assumptions in deposition and surface water models affect predicted CL exceedance?		■	■									■	■			
	W2. a) How many of the 7 lakes with predicted pH change >0. 1 *actually* acidify under KMP, and to what extent?													■			
	b) Are additional lakes suggested by MOE (MOE-3 and MOE-6) likely to receive deposition in excess of critical load?		■										■	■			
	c) What is the chemical status of insensitive lakes used in the biological program?													■			
	W3. What is the status of fish communities in the potentially vulnerable lakes that can be safely accessed for fish sampling?														■		
	W4. If some potentially vulnerable lakes show an acidifying trend, do they also show changes in their fish communities?														■		
	Is the increased SO_2 having an impact on lakes and streams, and on aquatic biota?													■	■		■
	What is the frequency and magnitude of episodic events?															■	

Appendix B. Checklist of Plants Potentially Sensitive to SO_2

Presence/absence of the following species will be noted during regular visual inspections for vegetation injury from SO_2:

- ☐ *Amelanchier alnifolia* (Saskatoon berry)
- ☐ *Aralia nudicaulis (*wild sarsaparilla,)
- ☐ *Cornus stolonifera* (red-osier dogwood)
- ☐ *Disporum hookeri* (Hooker's fairybells)
- ☐ *Dryopteris expansa* (spiny wood fern; spreading wood fern)
- ☐ *Epilobium angustifolium* (fireweed)
- ☐ *Lycopodium clavatum* (running club-moss)
- ☐ *Menziesia ferruginea* (fool's huckleberry, false azalea)
- ☐ *Pteridium aquilinum* (bracken fern)
- ☐ *Rosa acicularis* (prickly wild rose)
- ☐ *Rubus parviflorus* (thimbleberry)
- ☐ *Rubus spectabilis* (salmonberry)
- ☐ *Senecio triangularis* (arrowleaf ragwort; arrow-leaved groundsel)
- ☐ *Symphoricarpos albus* (common snowberry)
- ☐ *Vaccinium alaskaense* (Alaska blueberry)
- ☐ *Vaccinium membranaceum* (black blueberry; black huckleberry; thinleaf huckleberry)
- ☐ *Vaccinium ovalifolium* (oval-leaf blueberry)
- ☐ *Vicia Americana Vicia Americana* (American vetch)
- ☐ *Abies amabilis* (amabilis fir; Pacific silver fir)
- ☐ *Abies lasiocarpa* (subalpine fir)
- ☐ *Acer glabrum* (Douglas maple)
- ☐ *Alnus crispa* (green alder)
- ☐ *Alnus tenuifolia* (mountain alder)
- ☐ *Betula papyrifera* (paper birch)
- ☐ *Crataegus douglasii* (black hawthorne)
- ☐ *Pinus contorta* (lodgepole pine; shore pine)
- ☐ *Populus tremuloides* (quaking aspen; trembling aspen)
- ☐ *Populus trichocarpa* (black cottonwood)
- ☐ *Prunus pensylvanica* (pin cherry)
- ☐ *Prunus virginiana* (choke cherry)
- ☐ *Sorbus scopulina* (western mountain-ash)
- ☐ *Sorbus sitchensis* (Sitka mountain-ash)
- ☐ *Tsuga heterophylla* (western hemlock)

Note that some species may locally be known by different common names than those listed above (which were obtained from BC eFlora).

Sources:

BC eFlora (http://www.geog.ubc.ca/biodiversity/eflora/) accessed September 9, 2013.

Flagler, R.B. 1998. Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas. Pittsburgh, PA: Air & Waste Management Association.

Pojar, J. and A. MacKinnon (eds.) 1994. Plants of Coastal British Columbia: Including Washington, Oregon and Alaska. Lone Pine Publishing, 527 pp.

Appendix C. Quantitative Thresholds for Lakes and Streams and Aquatic Biota

The quantitative thresholds for lakes and streams and aquatic biota were specified in Tables 8.6-5 to 8.6-7 of the STAR (ESSA et al. 2013), and are reproduced below. Examples of lake specific thresholds for pH, ANC and SO4 are provided in Table 27 of Appendix H.

Likelihood (as per definition below)	**Consequence** (as per definitions below)				
	1 – Minor	2 – Medium	3 – Serious	4 – Major	5 – Catastrophic
A – Almost Certain	**Moderate**	**High**	**Critical**	**Critical**	**Critical**
B – Likely	**Moderate**	**High**	**High**	**Critical**	**Critical**
C – Possible	**Low**	**Moderate**	**Moderate**	**High**	**Critical**
D – Unlikely	**Low**	**Low**	**Moderate**	**Moderate**	**Moderate**
E – Very Unlikely	**Low**	**Low**	**Moderate**	**Moderate**	**Moderate**

Quantitative definitions of the five Likelihood levels:

A – Almost Certain	B – Likely	C – Possible	D – Unlikely	E – Very Unlikely
Predicted deposition ≥10 meq/m^2/yr **above CL**	Predicted deposition 0 to 10 meq/m^2/yr **above CL**	Predicted deposition 0 to 10 meq/m^2/yr **below CL**	Predicted deposition 10 to20 meq/m^2/yr **below CL**	Predicted deposition more than 20 meq/m^2/yr **below CL**

Quantitative definitions of the five Consequence levels:

1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
<5 % of study area lakes exceed CL AND **0** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**5-10 %** of study area lakes exceed CL AND **0** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**>10-15 %** of study area lakes exceed CL OR **1-2** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**>15-25 %** of study area lakes exceed CL OR **3-4** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**>25 %** of study area lakes exceed CL OR **5+** sampled streams exceed CL OR Lakelse Lake exceeds CL

Figure 9 shows pH levels at which biologically significant change is expected in aquatic biota.

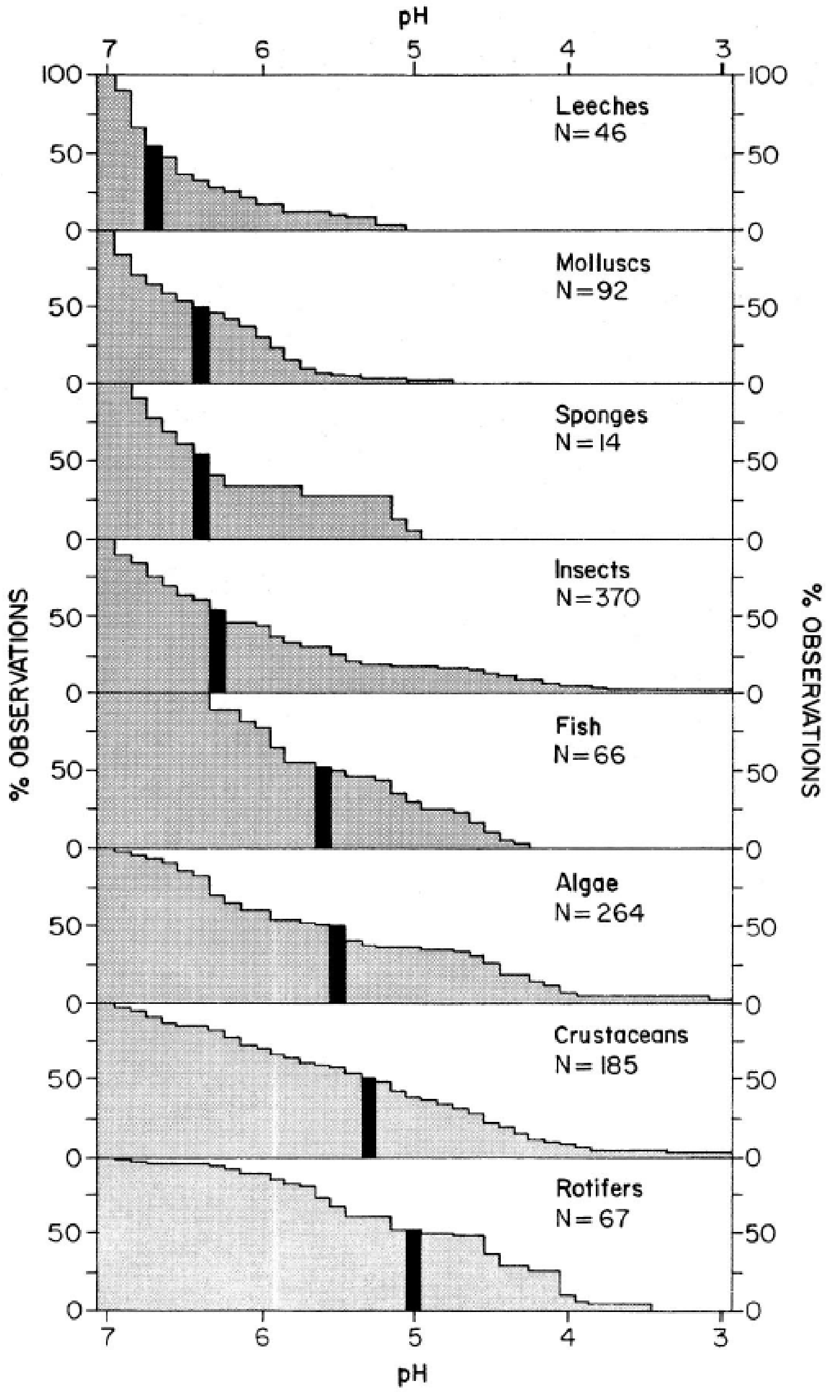

Figure 9. Cumulative frequency distribution of minimum pH values for field observations of aquatic taxa, showing percent reduction in species along a pH continuum. (The medial minimum pH value is indicated by the solid bar.) From: Eilers et al. 1984.

Appendix D. Lake Rating – Method and Results

Rating of the 10 vulnerable lakes (Figure 6) is needed for determining mitigation thresholds for the Water chemistry KPI (described in Section 6). This appendix describes the method used to determine the relative rating of these lakes, and presents the results.

The following method was used in rating the lakes:

1. Determine the rating criteria (Table 21).
2. Document the criteria for each lake (Table 22).
3. For each criterion, assign each lake a rating of Low, Medium, or High (Table 22).
4. Assign an overall rating Low, Medium, or High for each lake within the set of 10 acid-sensitive lakes, across all criteria (Table 23 and Table 24).

The relative rating of each lake within the 134 lakes > 1 ha in size within the study area was considered, recognizing that a lake could have a High relative rating within the set of acid-sensitive lakes, but a low relative rating within the overall study area. For the few criteria where this information was available, however, the ratings within this larger context did not differ appreciably from the ratings already assigned when looking just at the 10 vulnerable lakes.

The results of this rating exercise will help inform decisions regarding lake liming if the receptor-based mitigation threshold (described in Section 6) is reached, with the intention of protecting lakes of particular public interest.

Table 21. Criteria for rating of 10 lakes with either CL exceedance or predicted ΔpH > 0.1.

Criteria	Sources Sought for the Information
1. Accessibility and non-recreational use by people (presence/absence of road and trails for access; residences on shoreline; water licences; drinking water, industrial, irrigation or livestock use)	▪ Google Earth and BC Watershed Atlas maps ▪ Local MOE / FLNRO fish biologists[27] and angling / recreational groups; traditional knowledge ▪ Spreadsheet completed by Shauna Bennett of Limnotek in consultation with Fred Seiler ▪ Observations of existing trail, road, and ATV access from actual sampling of lakes ▪ Provincial water license database
2. Recreational value (e.g. angling, hiking, cross country skiing, snowmobiling, canoeing)	▪ Local MOE / FLNRO fish biologists ▪ Angling / recreational groups ▪ Recreational map for Northern BC
3. Lake surface area, which is a general indicator of fish biomass, diversity, habitat connectivity and	▪ STAR ▪ BC Watershed Atlas, 2012

[27] Joe De Gisi and Jeff Lough, FLNRO.

Criteria	Sources Sought for the Information
food supply for downstream areas[28]	
4. Sustainable fish species present; history of stocking; stocking suitability; unique fish species or life histories (including genetically significant populations, i.e. kokanee); other unique biota besides fish (including rare species)	▪ STAR ▪ Fisheries Information Summary System (FISS)[29] ▪ DFO information on salmon distribution ▪ Local MOE / FLNRO fish biologists ▪ 2013 fish sampling on presence/absence for LAK006 (End Lake), LAK012, LAK023 (West Lake) and LAK044 ▪ Presence of lake inflows and outflows, for lakes where fish presence is unknown
5. Lake is habitat used by anadromous salmon for accessing spawning areas upstream or for rearing by juveniles; supports culturally important food fishery	▪ DFO information on salmon distribution ▪ FISS ▪ Local MOE / FLNRO fish biologists; First Nations ▪ Presence/absence of inflow streams observed during actual lake sampling in 2013
6. Influence of DOC and organic acids[30]	▪ From STAR Section 9.4.1.2.3 – based on anion content and retrospective predictions of original pre-industrial pH ▪ Inferred % of potential fish species that were present in pre-industrial times, and currently (based on literature curves)
7. Estimated mid-range lake volume and max residence time	▪ From Table 25

[28] Compared to small lakes of similar productivity which contain fish, large lakes with fish are generally rated more highly, since they will have more total fish biomass (i.e., total biomass = biomass / area * area), are likely to have more diverse fish habitats and species composition, are more likely to have inlets and outlets, and are more likely to contribute forage fish for downstream piscivorous fish.

[29] Presence of species in FISS indicates that species was present at one time, but species may or may not be present now; absence of species in FISS does not mean that it is not present now.

[30] If lake naturally has a low pH due to organic acids (especially a pH less than 5 – see Figure 9), this would result in lower fish species diversity and likely lower fish production.

Table 22. Criteria results for the 10 lakes vulnerable lakes, as well as their relative ratings. Sources are listed below the table. (Note: LAK012 is hydrologically connected to End Lake (LAK006).)

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
1. ACCESSIBILITY AND NON-RECREATIONAL USE BY PEOPLE	ATV access and existing trail into lake[13] good access from ski trails[1] No residences using it for drinking water[16] No irrigation or livestock use; possible silvicultural activities[15]	No road access[10] Accessibility is poor[1]; not accessible[2]	ATV access and existing trail into lake[13] Can get boat into lake on ATV trailer[13]; no official boat access[15] Good access from ski trails[1] No shoreline residences present[16] No irrigation or livestock use[15] Possible silvicultural activities[15]	Road access[3,11] No shoreline residences[16] Forestry campsite on east side of lake (where the road meets the lake), definite use of this area[15] No residences, no water licenses, no irrigation or livestock[15] West side of lake and creek has been logged –have since had a hard time getting conifers to grow[15]	No road access[10]; not accessible[2,15] Claque Mountain Trail (hiking & snowmobiling) in the vicinity, but isn't clear if it runs near this lake[5,6,7] Likely no water users[15]	No road access[10]; Poor to fair access[1,2]; nearest road is ~200 m away, allowing an inflatable boat to be packed in[3]; may be some trails along old logging roads[15] No shoreline residences visible[3] Lake has very large wood waste dump site located south of it; leachate coming from this site may affect water quality[15]	Road access[10]; large pull out on highway with 50m walk on a well worn and wide trail to lake shore[13] Residence to the north of the lake may have a septic field[1] Water licence in lake for residence to the north[7]	Inaccessible mountain lake[3] Possible hiking trails[15]	No road access[10]; not accessible[2]	No road access[10]; not accessible[2]
Relative rating:	Medium	Low	Medium	High	Low	Low	High	Low	Low	Low
Notes on Rating:	Road access lakes are rated High; good ATV access lakes are rated Medium; and the rest are rated Low. Liming is most feasible in lakes with boat access.									
2. RECREATIONAL VALUE	Ski trails[1]; roads present to lakes north & south of this lake, both of which appear to be connected to LAK012 by	Possibly fishing, hiking, snowshoeing, cross country skiing, snow-mobiling[15]	Ski trails[1] Definite ATV, snowmobile use; fishing, boating, photography, hiking, snowshoeing, hunting; and	Campsite beside lake[1]; forest rec-reation site[7] Trails around lake; ATVs use old forestry roads around it; used for	Possibly hiking, snowshoeing, cross country skiing and snowmobiling[1,5]	Hiking[15]	Swimming, skiing, skating[15]	Hiking[15]	No information, but isolation and lack of access (criterion #1) suggests low recreational value	No information, but isolation and lack of access (criterion #1) suggests low recreational value

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
	creeks[2] ATV, snow-mobile use; fishing, boating, photography, hiking, snowshoeing, hunting; likely has a trapline around it[15]		probably is a trapline around it[15]	snowmobiling, hiking, angling, canoeing, hunting, and trapping; road to lake is not plowed in the winter so would be far for CC skiing[15]						
Relative rating:	High	Medium	High	High	Medium	Medium	High	Medium	Low	Low
Notes on rating:	Lakes with multiple known recreational uses are rated High, lakes with a few possible recreational uses are rated Medium, and lakes with no known recreational uses are Low.									
3. LAKE SURFACE AREA	2.3 ha [2,9] Ranks 57 among 134 lakes >1 ha (in the top 60%)	5.7ha [2,9] Ranks 28 among 134 lakes >1 ha (just below the top 20%)	10.2 ha [2,9] Ranks 14 among 134 lakes >1 ha (in the top 20%)	6.8 ha [2,9] Ranks 24 among 134 lakes >1 ha (in the top 20%)	1.0 ha [2,9] Ranks 127 among 134 lakes >1 ha (in the bottom 30%)	1.5 ha [2,9] Ranks 92 among 134 lakes >1 ha (in the bottom 30%)	2.0 ha [2,9] Ranks 66 among 134 lakes >1 ha (in the top 60%)	1.6 ha [2,9] Ranks 83 among 134 lakes >1 ha (just under the top 60%)	1.5 ha [2,9] Ranks 89 among 134 lakes >1 ha (just under the top 60%)	1.8 ha [2,9] Ranks 72 among 134 lakes >1 ha (in the top 60%)
Relative rating:	Low	Medium	High	Medium	Low	Low	Low	Low	Low	Low
Notes on Rating:	Of the 134 lakes in the study area >1 ha, Lakelse Lake (1,374.4 ha) and Jesse Lake (1,166.6 ha) are exceptionally large in surface area, two orders of magnitude larger than the third largest lake (Kitelse Lake, at 30.8 ha). Vulnerable lakes within the top 15 largest lakes in the study area were rated High (only West Lake, which at 10.2 ha is the 14th largest lake). Lakes within the top 30 largest lakes were rated Medium (LAK022 and LAK023 (West Lake)), which were also larger than 5 ha, and ranked 28th and 24th in area , respectively). Other lakes were rated Low. Since 51% of the 134 lakes in the study area were less than 2 ha, areas significantly larger than 5 ha (at least double that size) seemed a reasonable distinction between Medium and Low.									
4. SUSTAINABLE FISH PRESENCE	EEM sampling in Oct 2013 using RIC and small mesh gill nets confirmed presence of cutthroat trout, dolly varden, coho, three-spine stickleback	Previously stocked (DFO)[1] Fish habitat inferred[14] Connection to Coldwater Creek[1] Should be accessible to freshwater fish based on stream gradients, although there	EEM sampling in Oct 2013 using RIC and small mesh gill nets confirmed presence of cutthroat trout, dolly varden, coho, three-spine stickleback	Kokanee, cut-throat caught 1990[1]; coho 1989[4]; Chinook and cutthroat (no date)[4]; coho, Chinook, stickleback, cutthroat[2] EEM sampling using RIC and small mesh gill nets in Oct 2013 showed residualized	Accessibility to fish unknown, anadromous fish unlikely [2,15]	BC Watershed Atlas infers accessibility to freshwater fish based on stream gradients[14] Current production may be relatively low given the high concentration of organic acids and low pH value[2]	Was stocked ~ 25 years ago (anecdotal) but fish have all died off[15] EEM sampling in Oct 2013 using RIC and small mesh gill nets showed no fish present and no inflow or outflow stream	Not accessible to fish[14] Most likely none; feeds Coldwater Creek – an important fish stream in the Lakelse Watershed[15]	BC Watershed Atlas infers accessibility to freshwater fish based on stream gradients[14] Current production may be relatively low given the high concentration of organic acids and naturally low	BC Watershed Atlas infers accessibility to freshwater fish based on stream gradients[14] Current production may be relatively low given the high concentration of organic acids and naturally low

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
		are no empirical observations of fish recorded in the Atlas for this lake[14] Unknown, but there could be cutthroat present[15]		coho (to be confirmed with DNA analysis) plus three-spine stickleback					pH[2]	pH[2]
Relative rating:	High	Medium	High	Medium	Medium	Medium	Low	Low	Medium	Medium
Notes on Rating:	LAK012, End Lake (LAK006), West Lake (LAK023) and LAK044 were sampled for fish in 2013 as part of the EEM Program, and these lakes have the highest level of certainty regarding fish composition. Confirmed fish presence in the presence of outflow streams rates High. Confirmed fish presence with ephemeral presence of outflows (West Lake) rates Medium. For the other lakes, important information includes fish observations in the Watershed Atlas for *observed fish habitat*[12], and estimates of *inferred fish habitat* and *non-fish habitat* based on stream gradients[14]. Of the 134 lakes >1 ha in the study area, 11 lakes have *observed fish habitat* (including the lakes rated here as High, with fish presence confirmed by the Oct 2013 EEM fish sampling), 76 have *inferred fish habitat* (including the lakes rated here as Medium), 33 have *non-fish habitat* (including the lakes rated here as Low), and 14 were rated *unknown* (including LAK044, which was subsequently confirmed by fish sampling in 2013 to have no fish and therefore rated Low).									
5. HAB ITAT USE BY ANADROMOUS SALMON	Presence of coho confirmed by EEM sampling in 2013	Inferred[14]	Observed[12] Presence of coho confirmed by EEM sampling in 2013	Observed[12] Presence of residualized coho (to be confirmed with DNA) in EEM sampling in 2013	Anadromous fish unlikely[15]	Inferred[14]	No fish present in EEM 2013 sampling (see criterion #4)	Non-habitat[2] No[15]	Inferred[14]	Inferred[14]
Relative rating:	High	Medium	High	Medium	Low	Medium	Low	Low	Medium	Medium
Notes on rating:	Confirmation of the presence of anadromous salmon (coho) by sampling in 2013 results in a High rating. Residualized / resident coho were detected in West Lake, but appear not to be anadromous because outflows are only ephemeral. Lakes with inferred fish accessibility are rated Medium. Lakes with confirmation of no fish under criterion #4 are rated Low.									
6.-INFLUENCE OF DOC AND ORGANIC ACIDS	26% organic ions; est. pre-industrial pH 5.74[2] (53% of potential fish species present[8]); current pH 5.64[2] (51% of potential fish species	35% organic ions; est. pre-industrial pH 6.11[2] (77% of potential fish species present[8]); current pH 5.92[2] (60% of potential fish species	34% organic ions; est. pre-industrial pH 6.02[2] (71% of potential fish species present[8]); current pH 5.79[2] (54% of potential fish species	36% organic ions; est. pre-industrial pH 5.96[2] (64% of potential fish species present[8]); current pH 5.70[2] (52% of potential fish species	25% organic ions; est. pre-industrial pH 5.77[2] (54% of potential fish species present[8]); current pH 4.98[2] (26% of potential fish species	81% organic ions; est. pre-industrial pH 4.92[2] (25% of potential fish species present[8]); current pH 4.68[2] (18% of potential fish species	38% organic ions; est. pre-industrial pH 5.80[2] (54% of potential fish species present[8]); current pH 5.40[2] (47% of potential fish species	10% organic anions; est. original pH 6.0[2]	61% organic ions; est. pre-industrial pH 4.67[2] (18% of potential fish species present[8]); current pH 4.59[2] (12% of potential fish species	56% organic ions; est. pre-industrial pH 4.56[2] (10% of potential fish species present[8]); current pH 4.5[2] (9% of potential fish species

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
	present[8], for a loss of 2% relative to pre-industrial conditions); predicted future pH 5.51[2] (48% of potential fish species present[8] for a loss of 5% relative to pre-industrial conditions)	present[8] for a loss of 17% relative to pre-industrial conditions); predicted future pH 5.54[2] (49% of potential fish species present[8] for a loss of 28% relative to pre-industrial conditions)	present[8] for a loss of 17% relative to pre-industrial conditions); predicted future pH 5.31[2] (46% of potential fish species present[8] for a loss of 25% relative to pre-industrial conditions)	present[8] for a loss of 12% relative to pre-industrial conditions); predicted future pH 5.16[2] (38% of potential fish species present[8] for a loss of 26% relative to pre-industrial conditions)	present[8] for a loss of 28% relative to pre-industrial conditions); predicted future pH 4.60[2] (12% of potential fish species present[8] for a loss of 42% relative to pre-industrial conditions)	present[8] for a loss of 7% relative to pre-industrial conditions); predicted future pH 4.48[2] (9% of potential fish species present[8] for a loss of 16% relative to pre-industrial conditions)	present[8] for a loss of 7% relative to pre-industrial conditions); predicted future pH 4.86[2] (24% of potential fish species present[8] for a loss of 30% relative to pre-industrial conditions)		present[8] for a loss of 6% relative to pre-industrial conditions); predicted future pH 4.53[2] (10% of potential fish species present[8] for a loss of 8% relative to pre-industrial conditions)	present[8] for a loss of 1% relative to pre-industrial conditions); predicted future pH 4.44[2] (8% of potential fish species present[8] for a loss of 2% relative to pre-industrial conditions)
Relative rating:	Medium	Medium	Medium	Medium	Medium	Low	Medium	High	Low	Low
Notes on rating:	A High rating is assigned to lakes where organic anions (i.e., natural acidification) make up < 25%, of the total anions (i.e., if they have a low pH, this is more likely to be related to pollution). A Medium rating is assigned to lakes with organic acid influence (25-50% organic anions), where natural acidification is important in addition to any pollution effects. A Low rating is assigned to lakes that are dominated by organic acids (> 50% organic anions), and lakes were naturally acidified prior to any pollution sources.									
7. ESTIMATED MIDRANGE LAKE VOLUME & MAXIMUM RESIDENCE TIME	80,530 m^3 0.156 yrs	580,128 m^3 2.616 yrs	584,232 m^3 1.089 yrs	182,857 m^3 0.758 yrs	156,726 m^3 1.273 yrs	175,186 m^3 1.185 yrs	300,832 m^3 7.165 yrs	8,028 m^3 0.012 yrs	77,707 m^3 0.058 yrs	116,897 m^3 0.400 yrs
Relative rating:	Low	Medium	Medium	Medium	Medium	Medium	High	Low	Low	Low
Notes on rating:	Lakes with longer residence times have a slower rate of response to changes in acid loading, and will be more suitable sites for liming. Lakes with maximum residence time greater than 3 years are rated High. Lakes with maximum residence time between 1 and 3 years are rated Medium. Lakes with maximum residence time less than 1 year are rated Low.									

Sources:

[1] File "*Lake Recce Summary 14 June2013.xls*" prepared by Limnotek; information on access collected from maps, Google Earth, and local knowledge of field technicians who live in Terrace

[2] STAR (ESSA et al. 2013)

[3] Google Earth map

[4] BC Fisheries Information Summary System (of the 10 vulnerable lakes, only West Lake [ID 00012KITR] and End Lake [ID 00146LKEL] represented in the database)

[5] Kitimat recreation trails map (http://www.for.gov.bc.ca/dkm/recreation/kitimat/kitimat_rec.PDF)

[6] Clague Mountain Trail map (http://www.recsiteimages.tca.gov.bc.ca/REC6595/sitemaps/Mt%20Clague%20SummerTrail%20Exhibit%20%27A%27.pdf)

[7] BC iMap 2.0 (http://maps.gov.bc.ca/ess/sv/imapbc/)

[8] Eilers et al. (1984) Figure 1 showing expected biological responses to declining pH

[9] Field sampling data summarized by Limnotek in "*all 134 lakes sorted by area.xlsx*"

[10] Field sampling data summarized by Limnotek in "*Rio Tinto Alcan Field Data 2012 10Jan2013 for MOE.xlsx*"; the access information in this file was collected in an overflight and was not ground-truthed

[11] Christopher Perrin, Limnotek (email communication dated Sept. 19, 2013)

[12] BC Watershed Atlas

[13] Field notes from ground reconnaissance by Limnotek in August 2013, "*Field Notes_26AUG2013.pdf*"

[14] BC MOE, 2011. Fish Passage GIS analysis, FishHabitat [data set]. Craig Mount, MOE [distributor]

[15] Mitch Drewes, Hidden River Environmental Mgmt., Terrace BC (recommended by Markus Feldhoff, DFO)

[16] Observations during sampling of water and fish in 2013

Table 23. Method used to combine ratings on individual criteria into the overall ratings shown on the bottom row of Table 24.

Lakes must have ratings within the shaded categories to be assigned the corresponding overall rating. Criteria for which all three ratings are shaded (Low, Medium and High) had less weight on the overall rating (e.g. criterion 7) than criteria for which only a High value was required for an overall rating of High (e.g., criteria 2, 4 and 5).

Overall Rating	Criteria	Required Ratings		
		High	Medium	Low
High	1. ACCESSIBILITY AND USE BY PEOPLE	■	■	
	2. RECREATIONAL VALUE	■		
	3. LAKE SURFACE AREA	■	■	
	4. SUSTAINABLE FISH PRESENCE	■		
	5. HABITAT USE BY ANADROMOUS SALMON	■		
	6.-INFLUENCE OF DOC, ORGANIC ACIDS	■	■	
	7. EST. LK VOLUME & RESIDENCE TIME	■	■	■
Medium	1. ACCESSIBILITY AND USE BY PEOPLE	■	■	■
	2. RECREATIONAL VALUE	■	■	
	3. LAKE SURFACE AREA	■	■	
	4. SUSTAINABLE FISH PRESENCE	■	■	
	5. HABITAT USE BY ANADROMOUS SALMON	■	■	
	6. INFLUENCE OF DOC, ORGANIC ACIDS		■	
	7. EST. LK VOLUME & RESIDENCE TIME	■	■	■
Low	1. ACCESSIBILITY AND USE BY PEOPLE	■	■	■
	2. RECREATIONAL VALUE	■	■	■
	3. LAKE SURFACE AREA		■	■
	4. SUSTAINABLE FISH PRESENCE		■	■
	5. HABITAT USE BY ANADROMOUS SALMON		■	■
	6. INFLUENCE OF DOC, ORGANIC ACIDS		■	■
	7. EST. LK VOLUME & RESIDENCE TIME	■	■	■

Table 24. Rating results for the 10 lakes with either CL exceedance or predicted ΔpH > 0.1. Lakes with an asterisk (*) were sampled in 2013 and have high certainty on criteria 4 and 5.

Criteria	LAK012*	LAK022	End Lake (LAK006)*	West Lake (LAK023)*	LAK028	LAK042	LAK044*	LAK047	LAK054	LAK056
1. ACCESSIBILITY AND USE BY PEOPLE	M	L	M	H	L	L	H	L	L	L
2. RECREATIONAL VALUE	H	M	H	H	M	M	H	M	L	L
3. LAKE SURFACE AREA	L	M	H	M	L	L	L	L	L	L
4. SUSTAINABLE FISH PRESENCE	H*	M	H*	M*	M	L	L*	L	M	M
5. HABITAT USE BY ANADROMOUS SALMON	H	M	H	M	L	M	L	L	M	M
6.-INFLUENCE OF DOC, ORGANIC ACIDS	M	M	M	M	M	L	M	H	L	L
7. EST. LK VOLUME & RESIDENCE TIME	L	M	M	M	M	M	H	L	L	L
OVERALL RATING	**H**[31]	**M**	**H**	**M**	**L**	**L**	**L**	**L**	**L**	**L**

[31] LAK012 would rate "M" if it were isolated (due its small size, see Table 23), but since it is connected to End Lake (rated H) it should also be rated H.

Appendix E. Fish Sampling Locations and Method

Fish sampling will occur in seven lakes: four vulnerable lakes which can be safely accessed, and three reference lakes (Figure 10).

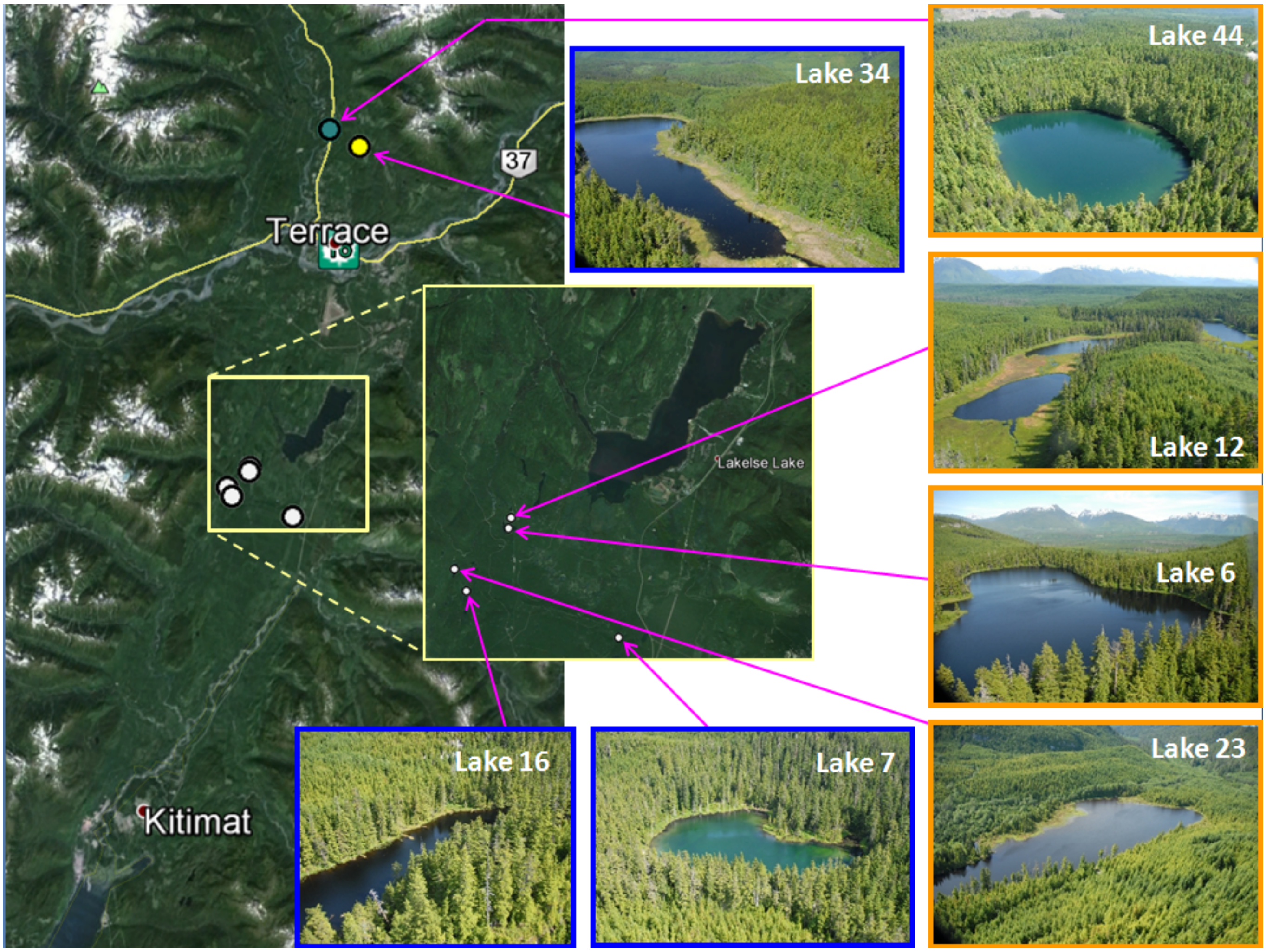

Figure 10. Map of the seven lakes that will be sampled for fish presence/absence. The four vulnerable lakes (Lakes 6, 12, 23 and 44) are indicated by orange borders around their photographs, and reference Lakes 7, 16 and 34 are indicated by blue borders.

Fish sampling will be scheduled for a time when water temperature in the epilimnion (surface mixed layer if the lake is density stratified) or the complete water column if no stratification is present is 7-13°C. Fish capture using gill nets is known to be most effective in this temperature range (Ward et al. 2012). Temperatures >13ºC may cause unacceptable fish mortality while temperatures <7ºC reduce fish activity and catch rates in passive gears such as gill nets. Based on available information for lakes in the Kitimat Valley, this temperature range is likely to occur in the latter half of September or early October.

Fish sampling will be done using gill nets. Two standard RIC nets (RIC 1997) and two small mesh nets will be fished in each lake using standard overnight methods (RIC 1997). The nets will be installed in late afternoon and recovered the following morning. One floating and one sinking RIC standard gill net (RIC 1997) will be used, each having dimensions of 91.2 x 2.4 m with six panels of different mesh sizes (25, 89, 51, 76, 38, and 64 mm stretched mesh). One floating and one sinking fine mesh gill net will be used to capture small underyearling fish. The fine mesh nets will have dimensions of 1.8 x 12.4 m with four panels of different small meshes (12.5, 19, 16, 25 mm stretched mesh). Material for the small mesh netting will be uncoloured monofilament <0.13 mm for the three smallest meshes and 0.18 mm for the largest mesh size.

The nets will be placed in habitat considered optimal for catching fish. The crew will deploy the gill nets and record coordinates using a GPS receiver. Procedures follow standard methods for gill netting by Lester et al (2009), Appelberg (2000), and Morgan and Snucins (2005). Use of sinking and floating nets will facilitate sampling of most depths in each lake. Various rigging will be used to either sink a net or float a net to a specific depth to achieve collection of samples from target depths.

References:

Appelberg, M. 2000. Swedish standard methods for sampling freshwater fish with multi-mesh gillnets. Fiskeriverket Information 2000:1. 29 pp.

Morgan, G. E. and E Snucins. 2005. Manual of Instructions and Provincial Biodiversity Benchmark Values Manual of Instructions for NORDIC Index Netting. Ontario Ministry of Natural Resources. 47 pp.

RIC. 1997. Fish Collection Methods and Standards. Prepared by the B.C. Ministry of Environment, Lands and Parks, Fish Inventory Unit for the Aquatic Ecosystems Task Force, Resources Inventory Committee (RIC).

Ward, H. G. M., P. J. Askey, J. R. Posta, D. A. Varkey, and M. K. McAllister. 2012. Basin characteristics and temperature improve abundance estimates from standard index netting of rainbow trout (*Oncorhynchus mykiss*) in small lakes. Fisheries Research, 131-133: 52-59.

Appendix F. State-of-Knowledge Summary for Liming of Soils

One of the long-term legacies of acid rain has been identified as calcium depletion in soils (Lawrence et al. 1999; Huntington et al. 2000; Watmough and Dillon 2003a; Yanai et al. 2005). Calcium (Ca) is a macronutrient for trees (Lawrence et al. 1999) and other biota, and is important for sustaining growth (Lawrence et al. 1995). Acid deposition leaches calcium from the soil (Driscoll et al. 2001; Likens et al. 1998), making less available for uptake by roots to replenish losses in the canopy. Losses of calcium in the soil make forest ecosystems increasingly sensitive to continuing inputs of acid (Likens et al. 1998), and threaten forest health and productivity (Watmough and Dillon 2003b). Site-specific application of buffering compounds may be effective. The wide range of success of such treatments suggests a need for testing specific locations on a pilot scale.

Lime and wood ash are used for forest soil amelioration, with the objective of reducing soil acidity, increasing calcium concentrations in trees, and improving tree growth (Reid and Watmough 2013). Soil pH, calcium foliar concentration, and various tree growth metrics are typically used to measure success. Other useful performance metrics include base saturation, ectomychorrhizae (ECM) root colonization, and indices of microbial diversity, richness and abundance (Reid and Watmough 2013).

The two most common buffering compounds used in liming research are calcite (calcium carbonate, limestone, $CaCO_3$) and dolomite ($CaMg(CO_3)_2$), but wollastonite (CaSiO3), gypsum (CaSO4), calcium nitrate (Ca(NO3)2), and calcium chloride (CaCl2) can also be used (Reid and Watmough 2013). Solubility affects the response of soils to calcium treatment. Calcium in wood ash is more soluble than calcium in lime compounds (Meiwes 1995). In wood ash, calcium is typically present as $CaCO_3$, but concentrations tend to be highly variable and inferior to those in liming agents (Demeyer et al. 2001). Potentially toxic elements such as cadmium (Cd) and lead (Pb) may also be present in wood ash (Demeyer et al. 2001; Aronsson and Ekelund 2004).

On the whole, additions of calcium to soils have not been universally beneficial. In their meta-analysis of 350 independent trials from 110 peer-reviewed liming and wood ash studies, Reid and Watmouth (2013) found that treatment efficacy depends on a number of inter-related factors, including soil type (organic vs. mineral), time since treatment, material used (lime vs. wood ash), dose, forest stand age, and tree species (hardwood vs. softwood). For example, organic soils exhibited a larger increase in pH following calcium addition than did mineral soils (mean increases of 1.04 and 0.36 pH units respectively), and organic soils responded better to lime than to wood ash additions. Young forest stands (<50 yrs) on organic soils that were treated with lime showed the greatest mean increase in pH (1.68 units). In mineral soils, the greatest mean increase in pH (0.64 pH units) occurred in initially acidic soils (pH <4.5) that received higher treatment doses (>5000 kg/ha). The largest increase in base saturation (42.4%)

occurred in the organic soils of softwood stands where sampling took place ≥10 years after treatment. Foliar calcium concentration showed the highest increase in limed stands (48.5% over control) as compared to stands treated with wood ash (13.8% over control). Limed hardwood stands treated with high doses (>5000 kg/ha) exhibited the greatest mean increase in foliar calcium concentration (92.5% over control). As a performance measure, tree growth showed the highest degree of variation in the analysed trials, with time since treatment, initial soil pH, and tree species all affecting the response to treatment. The highest mean increase in growth (116% over control) occurred for softwoods on soils with initial pH >4.5 and where measurements were taken more than 10 years after treatment. For sites with initially acidic soils (pH <4.5), hardwoods showed greater growth increases than softwoods, especially at higher doses (>5000 kg/ha).

When soils are treated with calcium, the lime or wood ash is applied to the upper organic horizon and takes time to leach down into the mineral soil. Short-term trials may fail to detect effects in the mineral horizon. Recycling of calcium by forests may also serve to hold the added calcium in the organic layer (Reid and Watmough 2013). Recent research on sugar maple stands in Quebec demonstrated that lime addition on the forest soil surface can take more than a decade to reach and influence mineral soils (Moore et al. 2012). Additionally, the response of organic soils to calcium additions may be affected by forest stand age. Older stands have higher calcium demands than younger stands, resulting in fewer of the hydrogen ions in soil being replaced by calcium (Reid and Watmough 2013). Additionally, young stands are able to mobilize more calcium than they can accumulate in biomass, resulting in higher concentrations of calcium in the soil exchangeable pool (Johnson et al. 1994). More calcium in the exchangeable pool could lead to sustained positive effects on foliar calcium concentration and tree growth (Reid and Watmough 2013).

Lime treatment produces a larger response in soil pH and foliar calcium concentration than wood ash, largely because the calcium content in lime compounds is higher than in the same mass of wood ash (Reid and Watmough 2013). Other treatment attributes that may affect response include method of application and calcium solubility. Higher liming rates produce a longer-lasting effect on soils than lower rates (Moore et al. 2012).

Initial soil pH, tree species (hardwood vs. softwood), and time since treatment all influence tree growth in response to soil amelioration with calcium. In the meta-analysis of calcium trials conducted by Reid and Watmough (2013), both hardwood and softwood stands exhibited the largest increase in growth on soils that were initially only moderately acidic (pH 4.5 - 6). The authors postulated that these sites may have been less limiting in terms of other nutrients (magnesium, potassium, nitrogen, phosphorus) than more acidic sites (pH <4.5). Calcium additions from liming or wood ash treatment can induce pronounced soil changes no matter the initial soil pH, but a growth response will not occur if other nutrients are also limiting. For example, Aronsson and Ekelund (2004) found that forest growth can be increased on wood ashameliorated peatlands rich in nitrogen. However, no change or even decreased growth occurred on nutrient-poor mineral soils treated with wood ash.

Growth effects from calcium treatment of soils also varied by tree species and time since treatment in the trials analysed by Reid and Watmough (2013). Within the hardwoods, sugar maple growth increased in response to calcium addition, American beech showed no change in growth, and black cherry growth declined. Such species-specific variability reflects the complexities inherent in the requirements for tree growth (Reid and Watmough 2013). Tree growth also takes time, and 50% of the trials in the analysis measured growth less than 6 years after treatment. The paucity of long-term trials may explain the substantial number of studies that reported no growth effect (Reid and Watmough 2013). Additionally, environmental conditions such as rainfall or pollutants may influence tree growth and vitality during the trial period, affecting site condition and treatment effects (Van der Perre et al. 2012).

In their review of wood ash trials in boreal forest and aquatic ecosystems, Aronsson and Ekelund (2004) concluded that the effects of calcium treatment on ground vegetation, fungi, soil microbes, and soil-decomposing animals were not very clear. The discrepancies between different studies could be largely explained by abiotic factors such as variation in fertility among sites, different degrees of stabilization, and wood ash dosage used, and different time scales among different studies. Given uncertainties about the efficacy of wood ash application, and the potential for biotoxic effects on both terrestrial and aquatic ecosystems, the authors recommended site-specific application practices, rather than broad and general wood ash application to forests.

References:

Aronsson, K.A. and. Ekelund, N.G.A. 2004. Biological effects of wood-ash application to forest and aquatic ecosystems. J. Enviro. Qual. 33: 1595-1605. Abstract only at: http://www.ncbi.nlm.nih.gov/pubmed/15356219. Accessed October 22, 2013.

Demeyer, A., J.C. Voundi Nkana, and M.G. Verloo. 2001. Characteristics of wood-ash and influence on soil properties and nutrient uptake: An overview. Bioresource Technology 77: 287-295.

Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C.Eager, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001a. Acidic deposition in the northeastern United States: Sources and inputs, ecosystem effects, and management strategies. BioScience 51(3):180-198

Huettl, R. and Zoettl, H. 1993. Liming as a mitigation tool in Germany's declining forests-reviewing results from former and recent trials. For. Ecol. Manage. 61: 325-338. Abstract only at: http://journals2.scholarsportal.info.cat1.lib.trentu.ca:8080/journal.xqy?uri=/03781127. Accessed October 21, 2013.

Huntington T., Hooper R., Johnson C., Aulenbac B., Cappellato R. and Blum, A. 2000. Calcium depletion in a Southeastern United States forest ecosystem. Soil Sci. Soc. Am. J. 64:1845-1858. Abstract only at: http://pubs.er.usgs.gov/publication/70022483. Accessed October 21, 2013.

Johnson, A.H., Anderson, S.B., Siccama, T.G. 1994. Acid rain and the soils of the Adirondacks: I. Changes in pH and available calcium 1930-1984. Can. J. For. Res. 24: 39-45

Lawrence, G.B., M.B. David, and W.C. Shortle. 1995. A new mechanism for calcium loss in forest-floor soils. Nature 378:162-165

Lawrence, G.B., M.B. David, G.M. Lovett, P.S. Murdoch, D.A. Burns, B.P. Baldigo, A.W. Thompson, J.H. Porter, and J.L. Stoddard. 1999. Soil calcium status and the response of stream chemistry to changing acidic deposition rates in the Catskill Mountains of New York. Ecological Applications. 9:1059-1072.

Likens, G.E., C.T. Driscoll, D.C. Buso, T.G. Siccama, C.E. Johnson, G.M. Lovett, T.J. Fahey, W.A. Reiners, D.F. Ryan, C.W. Martin, and S.W. Bailey. 1998. The biogeochemistry of calcium at Hubbard. Biogeochemistry 41:89-173.

Meiwes, K.J. 1995 Application of lime and wood-ash to decrease acidification of forest soils. Water Air Soil Pollut. 85: 143-152.

Moore, J-D., Ouimet, R. and Duchesne, L. 2012. Soil and sugar maple response 15 years after dolomitic lime application. For. Ecol. Manage. 281: 130-139.

Nilsson, S.I., Andersson, S., Valeur, I., Persson, T., Bergholm, J., and Wirén, A. 2001. The influence of dolomite on leaching and storage of C, N and S in a Spodosol under Norway Spruce (Picea abies (L.) Karst.). For. Ecol. Manage. 146: 57-75.

Reid, C. and S. Watmough. 2013 (in prep). Evaluating the effects of liming and wood-ash treatment on forest ecosystems through systematic meta-analysis.

Van der Perre, R., Jonard, M., André, F., Nys, C., Legout, A. and Ponette, Q. 2012. Liming effect on radial growth depends on time since application and on climate in Norway spruce stands. For. Ecol. Manage. 281: 59-67.

Watmough, S.A. and P.J. Dillon. 2003a. Base cation and nitrogen budgets for a mixed hardwood catchment in south-central Ontario. *Ecosystems* 6:675-693.

Watmough, S.A. and P.J. Dillon. 2003b. Calcium losses from a forested catchment in south central Ontario, Canada. *Environmental Science and Technology* 37:3085-3089.

Yanai, R.D., J.D. Blum, S.P. Hamburg, M.A. Arthur, C.A. Nezat, and Siccama, T.G. 2005. New insights into calcium depletion in northeastern forests. J. For. 103: 14-20.

Appendix G. State-of-Knowledge Summary for Liming of Lakes

Other than source control of emissions, the most effective mitigation strategy for managing acidic conditions in lakes, streams, or watersheds is liming (Olem 1990, Clair and Hindar 2005 – excerpts from these documents are included at the end of this appendix). Liming commonly results in significant positive physical, chemical, and biological changes in aquatic ecosystems. The pH, ANC, dissolved inorganic carbon, and calcium of surface waters generally increase with the addition of limestone. Concentrations of nutrients do not typically change, but liming increases nutrient cycling, decomposition, and primary productivity. Aluminum, iron, lead, manganese, and zinc – metals that may be toxic to aquatic biota – are sometimes lower in limed lakes due to precipitation, oxidation, surface adsorption, and ion exchange. Liming generally has positive impacts on fish, with successful reproduction and growth of resident and re-introduced species in many cases (Olem 1990). Despite its many benefits, liming may not restore the biota believed to be present prior to acidification, particularly if certain taxa have been eliminated due to a large reduction in lake pH for a considerable length of time. Liming cannot counteract the effects of acidic episodes from influent streams or from littoral zones. Other factors that distinguish limed lakes from their unacidified counterparts include the presence of precipitated metals, undissolved base material, elevated calcium levels, and the possibility of re-acidification between treatments (Olem 1990).

Studies completed since 1990 generally support the overall conclusions of Olem (1990) regarding the physical and chemical changes that occur following the liming of an acidic lake (e.g. see Clair and Hindar 2005). However, many post-1990 studies suggest that biological recovery in limed lakes is variable, and is not always as successful as reported by Olem (1990). While in many cases restocked fish populations were re-established (e.g., Sandøy and Romundstad 1995), unintended and undesired responses can include: instability of the fish community due to both chemical and biological factors (Appelberg et al. 1995, Nilssen and Wærvågen 2002); incomplete restoration of biota to the species mix present in unacidified lakes (Hultberg and Andersson 1982; Renberg and Hultberg 1992), though species diversity may be comparable (Appelberg et al. 1995, Hörnström et al. 1993); undesirably large expansions of macrophyte populations that take advantage of the more alkaline conditions (Roelofs et al. 1994). Recovery can be severely prolonged in strongly disturbed, chronically acidified ecosystems (Nilssen and Wærvågen 2002).

Emissions reduction at source is clearly a more permanent solution than liming, but it may not be the preferred solution if only a few lakes are affected, and source control involves other environmental impacts. Extensive liming efforts in Norway and Sweden have shown that systems that are treated before all fish species are lost, and before major dominance shifts occur within the macroinvertebrate community, recover the most quickly (Nilssen and Wærvågen 2002). For localized mitigation through liming, the most prudent approach for conserving fish populations and other biota in lakes considered to be valuable (and feasible for liming) would be to maintain their pH at close to their current level (i.e., preventative liming). Localized mitigation would involve occasional, careful additions of precisely estimated amounts of limestone to the lake surface to maintain lake pH at its current level (i.e., if the lake pH falls 0.3 units below its 2012 level, then restore it back to its 2012 level). Laboratory tests of collected lake water should be used to empirically determine the appropriate dosage, and develop a titration curve for each lake. Models could be used to check these estimates. However, it should be considered that liming will likely need to be redone on an ongoing basis (every few years) if the source of acidification remains unchanged. All of the European studies with long-term results showed that the termination of liming programs resulted in rapid reacidification and the reversal to pre-liming conditions (Clair and Hindar 2005).

The best candidates for liming (Weigmann et al. 1993) have the following characteristics:

- Softwater lakes with pH < 6.5 (true for all 10 acid-sensitive lakes in the Rio Tinto Alcan region);
- Large pH fluctuations (not known for these lakes, but could be determined by placing a pH sonde);
- Retention time > 3 months (need to know mean depth[32] to estimate this accurately, but can get a rough estimate from 2012 sampling – see Table 25);
- Evidence of historical fish populations (have anecdotal and survey data on this point for some lakes in the valuation table, and will have more detailed data from 2013 sampling); and
- Slow fish growth and low food production (can infer this from fish densities in 2013 sampling).

The New York Department of Environmental Conservation (1990) used somewhat different criteria for deciding which lakes were appropriate for liming, focusing on lakes with a pH < 5.7 and a retention time **less than** 6 months.

Clair and Hindar (2005) further emphasize the importance of proponents and regulators following a clear process to minimize ecological damage and maximize the chance of meeting their objectives. To achieve these conditions, Clair and Hindar suggest the following issues be carefully considered (2005, p. 18, emphasis added):

1. First, there needs to be a **good rationale to justify attempting to modify an ecosystem**, and the parts of the ecosystem in need of protection need to be clearly identified.
2. There must be **clear understanding of the target species life cycle**.
3. The proponents must have **reasonable expectations of what is achievable** with the methods they will be using.

[32] From the sampling conducted in 2012, we know the depth of lakes at the sampling point, but not the mean depth which requires a bathymetry survey. The depth of the lake at the sampling point is a rough estimate of the mean depth, but is driven by the safest place for the helicopter to hover, so the mean depth could be ~50% lower or higher than the sampled depth.

4. The proponents must have a **good understanding of the time to recovery** of the system.

Given the small size of the lakes of interest in the KMP study area, application of a limestone slurry from a tank onboard a boat would be the most cost-effective approach for road-accessible lakes, which ensures both rapid dissolution and accurate delivery across the lake surface (Olem 1990, pg. 15-59). Delivery of limestone by helicopter or fixed wing aircraft would be the only option for lakes which are not accessible by road, and the pros and cons would need to be carefully evaluated (e.g., safety, lake's value, degree of pH control); these methods have had mixed success (Olem 1990, pg. 15-61 to 15-63).

Table 25. Estimate of water retention[a] time (or residence time) for the ten acid-sensitive lakes. All but two lakes (LAK012 and LAK054) have more than a 3-month residence time.

SITE_ID	Lake Area (ha)	Depth at sampling point (m)	Water-shed Area (ha)	Runoff (m)	Estimated Midrange Lake Volume (m_3)	Estimated Midrange Residence Time (yr)	Min Residence Time (yr)	Max Residence Time (yr)	> 3 month residence time?
LAK006	10.25	5.7	91.2	0.88	584,232	0.726	0.363	1.089	YES
LAK012	2.30	3.5	90.1	0.86	80,538	0.104	0.052	0.156	NO
LAK022	5.74	10.1	39.9	0.83	580,128	1.744	0.872	2.616	YES
LAK023	6.77	2.7	40.3	0.90	182,857	0.505	0.253	0.758	YES
LAK028	1.02	15.5	11.9	1.58	158,726	0.849	0.424	1.273	YES
LAK042	1.46	12.0	37.2	0.60	175,186	0.790	0.395	1.185	YES
LAK044	2.01	15.0	9.9	0.64	300,832	4.777	2.388	7.165	YES
LAK047	1.61	0.5	42.9	2.41	8,028	0.008	0.004	0.012	NO
LAK054	1.52	5.1	125.3	1.61	77,707	0.038	0.019	0.058	NO
LAK056	1.77	6.6	27.3	1.60	116,897	0.267	0.133	0.400	YES

[a] Retention time (yr) = Lake Volume (m^3) / Annual Outflow (m^3/yr). This can be estimated from:
Retention time (yr) = [Lake Area (m^2) * Mean Depth (m)] / [Watershed Area (m^2) * Annual Runoff (m/yr)].

Summary from Olem 1990:

Acidic conditions in surface waters can be mitigated by adding alkaline materials to the lake, stream, or watershed or by less common methods. The primary objective is the maintenance of water quality suitable for the support of fish populations. The mitigation strategy most effective for mitigation of acidic conditions is the addition of limestone.

Conventional whole lake liming is a more established mitigation alternative than liming running waters or watersheds. Lakes have been the receptors most widely treated, primarily because they can be treated with a single application that may last several years. Limestone applications from boats or helicopters are generally the most effective techniques. Relatively few running waters have been treated to date[33]; permanent structures are generally required to provide continuous streamwater treatment. Treatment of the watershed to protect lakes and streams has been receiving increased interest in recent years. Watershed liming has been shown to last longer than surface water liming and may provide increased protection from episodic acidic conditions and leaching of trace metals. Little experience exists for watershed liming[34]; its use in the United States is experimental. Accurate methods are available for determining limestone doses required for treating lakes, streams, and watersheds, and for estimating lake reacidification rates.

The addition of base materials to surface waters commonly results in significant positive physical, chemical, and biological changes in aquatic ecosystems. Physical changes that normally occur in low humic waters after liming are decreased transparency and increased color and temperature. The pH, ANC, dissolved inorganic carbon, and calcium of surface waters generally increase after limestone addition. Concentrations of nutrients and organic matter do not significantly change after liming, but some studies have shown a response in limed lakes. Metals that may be toxic to aquatic organisms- particularly aluminum, iron, lead, manganese, and zinc- are sometimes lower in limed waters due to precipitation, oxidation, surface absorption, and ion exchange. Limestone addition often causes changes in lake sediments due primarily to the instantaneous adsorption of calcium.

Liming generally increases nutrient cycling, decomposition, and primary productivity and results in a positive response in aquatic biota. Liming often results in increased plankton biomass and considerable alteration in community structure of benthic macroinvertebrates. The effects of liming have been clearly favorable to fish populations. Liming has permitted the stocking of fish species previously lost form the system, introduction of new species, or the recovery of existing but stressed fish populations. Successful reproduction and growth of resident and reintroduced fish species have been developed in many limed surface waters. In a few isolated instances, liming has caused mortalities in resident fish populations due to metal toxicity, but the conditions causing the toxicity were not always clearly identified.

Restoration of water quality conditions to those believed to exist before acidification has not always resulted in restoration of the original biota. It may also be possible that liming cannot restore conditions exactly as they were before acidification. For example, whole-lake liming does not eliminate acidic episodes from influent streams or from littoral zones. Other factors also separate limes waters from their unacidified counterparts, including precipitated metals, undissolved base material, elevated calcium levels, and the possibility of reacidification between treatments.

[33] Significantly more experience and research on stream liming and watershed/catchment liming has accumulated since 1990 (e.g., see Clair and Hindar 2005 for a more recent review).
[34] See previous footnote.

Excerpts from Clair and Hindar (2005):

NOTE: the studies reviewed by Clair and Hindar (2005) concern freshwater systems with much more substantial levels of acidification than represented by pH thresholds identified in the present EEM. The predominant focus of research on liming has been highly acidified lakes in Europe and eastern North America, which have been exposed to heavy levels of deposition over decades. Consequently, compared to the context of the EEM, the pre-liming conditions of the lakes and streams described by Clair and Hindar (2005) represent systems with much higher levels of acidification, thus requiring more intensive liming treatments targeting greater changes in pH, and significant ecological degradation that has occurred over time. The possible application of liming within the EEM concerns a much smaller change in pH and a much more responsive timeframe for potential mitigation.

> Based on our analysis of the literature, we must come to the conclusion that with very few exceptions, the use of lime or dolomite on either catchments or water bodies is not deleterious to aquatic ecosystems either in the short or long term. The one exception to these conclusions is the liming of wetlands. (p. 116)
>
> Most of the studies we report on have been able to modify the chemistry of receiving waters to a desired state. Generally, the biological communities in rivers and lakes that have been limed tend to accumulate more acid-sensitive species, and have not shown any obvious further degradation in community composition or structure. However, returns to what may have been pre-acidification ecological conditions have been more elusive. An important reason for this is that the chemical changes brought about to streams, lakes, and catchments are usually temporary, as reacidification is bound to return ecosystems to their previous “damaged” state upon cessation of the liming effort. The reversion is immediate when liming streams and rivers, usually within a few years when liming lakes, and between 10 and 50 years when liming catchments. So the question that must be asked is whether liming is a worthwhile exercise in the long term. As we show that liming is not generally harmful to the environment, deciding whether or not to lime will involve a number of social, policy, and even philosophical considerations. (p. 116)
>
> The main shortcoming of liming programs is that ecosystems do not completely return to preacidification conditions for several reasons. First, unstable or inadequate chemistry conditions may occur when using unsuitable liming strategies. Secondly, species interactions and a lack of sources for sensitive species reintroduction will affect community composition. Generally, the papers quoted in this review show that targetted fish species usually, but not always, can be assisted in returning to viable numbers, as long as pH and ANC (and thus lower Ali) can be maintained over long periods of time and that restocking or protection against predators is done. More often than not, however, the rest of the ecosystem is never completely returned to pre-acidification conditions and the new communities may be relatively unstable and prone to large changes in composition. (p. 117)
>
> Ecosystem liming must be viewed as a tool to keep ecosystems or targetted fish populations from being irretrievably lost until nature can restore itself under less polluted conditions. It cannot be a substitute for pollution prevention, nor should it be used to create conditions that did not exist before the acidification problem existed. (p. 118)

References:

Appelberg, M., P-E. Lingdell, C. Andrén. 1995. Intergrate studies of the effect of liming acidified waters (ISELAW-Programme). Water, Air and Soil Pollution, 85: 883-888.

Clair, T.A. and A. Hindar. 2005. Liming for the mitigation of acid rain effects in freshwaters: A review of recent results. Environmental Review 13:91-128.

Hörnström, E., C. Ekström, E. Fröberg, J. Ek. 1993. Plankton and chemical-physical development in six Swedish west coast lakes under acidic and limed conditions. Canadian Journal of Fisheries and Aquatic Sciences, 50: 688-702.

Hultberg, H., I. Andersson. 1982. Liming of acidified lakes: induced long-term changes. Water, Air, and Soil Pollution, 18: 311-331.

H. Simonin. 1990. Final generic environmental impact statement on the New York State Department of Environmental Conservation Program of Liming Selected Acidified Waters. New York Department of Environmental Conservation, Division of Fish and Wildlife. 242 pp.

Nilssen, J.P., S.B. Wærvågen. 2002. Intensive fish predation: an obstacle to biological recovery following liming of acidified lakes? Journal of Aquatic Ecosystem Stress and Recovery 9: 73–84.

Olem, H. 1990. Liming acidic surface waters. Lewis Publishers, Chelsea, MI. 331 pp.

Renberg, I., H. Hultberg. 1992. A Paleolimnological assessment of acidification and liming effects on diatom assemblages in a Swedish lake. Canadian Journal of Fisheries and Aquatic Sciences, 49: 65-72.

Roelofs, J.G.M., T.E. Brandrud, A.J.P. Smolders. 1994. Massive expansion of Juncus bulbosus L. after liming of acidified SW Norwegian lakes. Aquatic Botany, 48: 187-202.

Rosseland, B.O., I.A. Blakar, A. Bulger, F. Kroglund, A. Kvellstad, E. Lydersen, D. H. Oughton, B. Salbu, M. Staurnes, R. Vogt. 1992. The mixing zone between limed and acidic river waters: complex aluminium chemistry and extreme toxicity for salmonids. Environmental Pollution, 78: 3-8.

Sandøy, S., A.J. Romundstad. 1995. Liming of acidified lakes and rivers in Norway: An attempt to preserve and restore biological diversity in the acidified regions. Water, Air and Soil Pollution, 85: 997-1002.

Weigmann, D.L., L.A. Helfrich, D.C. Josephson, R.M. Speenburgh. 1992. Guidelines for Liming Acidified Lakes and Ponds. Virginia Water Resources Research Center: Virginia Polytechnic Institute and State University, Blacksburg. 23 pp.

Additional references, not cited in this summary:

Henrikson, L., Y-W. Brodin. 1995. Liming of acidified surface waters: A Swedish synthesis. Springer-Verlag Berlin Heidelberg. 458 pp.

Renberg, I. T. Korsman, N.J. Anderson. 1993. A Temporal Perspective of Lake Acidification in Sweden. Ambio. , 22(5): 264-271.

Andersson, P., H. Borg, P. Kärrhage. 1995. Mercury in fish muscle in acidified and limed lakes. Water, Air, and Soil Pollution, 80: 889-892.

SverdrupH., P. Warfvinge. 1985. A reacidification model for acidified lakes neutralized with calcite. Water Resources Research, 21(9): 1374-1380.

Appendix H. Design Considerations for Detecting Trends in Lake Chemistry

The BC Ministry of Environment has requested a detailed description of the statistical and inferential methods to be used to evaluate the EEM triggers in Table 14, using both the key performance indicator of pH and other informative indicators such as ANC. The methods described below build on previous acidification studies, but will be further adapted based on detailed studies on lake chemistry being conducted in 2014.

The EEM triggers in Table 14 (decrease in lake pH of 0.3 pH units) are meant to result in the earliest possible detection of biologically significant acidification that is related to KMP. The following points help to provide a context for the methods described below:

1. No acidification would show patterns like those in Figure 11 (i.e., increases in SO_4 deposition and lake SO_4, but no change in lake in ANC or pH).
2. Acidification strongly related to KMP would generate the patterns shown in Figure 12 (i.e., increases in emissions of SO_2, deposition of SO_4 and lake [SO_4]; and decreases in lake ANC and pH).
3. Acidification unrelated to KMP could show patterns like those in Figure 13 (decreases in pH and ANC, no change in SO_4), but increases in other anions, such as NO_3 (other pollution sources), Cl (acidification due to deposition of seasalt in watersheds with organic acids) and/or organic anions (watershed releases due to changes in climate).
4. Combinations of natural and anthropogenic processes could result in patterns intermediate between Figure 12 and Figure 13. For example, releases of stored sulphate from wetlands or marine clays might cause episodic acidification, but would not be expected to show a long term, continued acidification trend correlated with changes in sulphate deposition.
5. Acidification trends are best detected by examining multiple indicators (deposition of SO_4, lake [SO_4], lake ANC, and lake pH) across multiple lakes with similar characteristics (Stoddard et al. 1996, 2003). Examining water quality trends jointly for the acid-sensitive lakes with similar characteristics (to be evaluated as part of the statistical power analysis) will provide much higher statistical power to evaluate trends than examining each lake's trends independently. Six of the seven acid-sensitive lakes in the EEM Program have similar pH levels (4.98 to 5.92), ANC (-4 to 57 µeq/l) and percentages of organic anions (25 to 28%), as shown in Table 26. Lake 042 has a somewhat lower pH (4.68) and ANC (-20 µeq/l) due its higher percent of organic anions (81%). Fortunately, Stoddard et al. (1996) found that lakes with low ANC and low DOC, as well as lakes with low ANC and high DOC, have relatively low year to year variability in ANC and pH, and therefore have relatively good statistical power for detecting trends compared to other types of lakes with higher ANC (Figure 16).

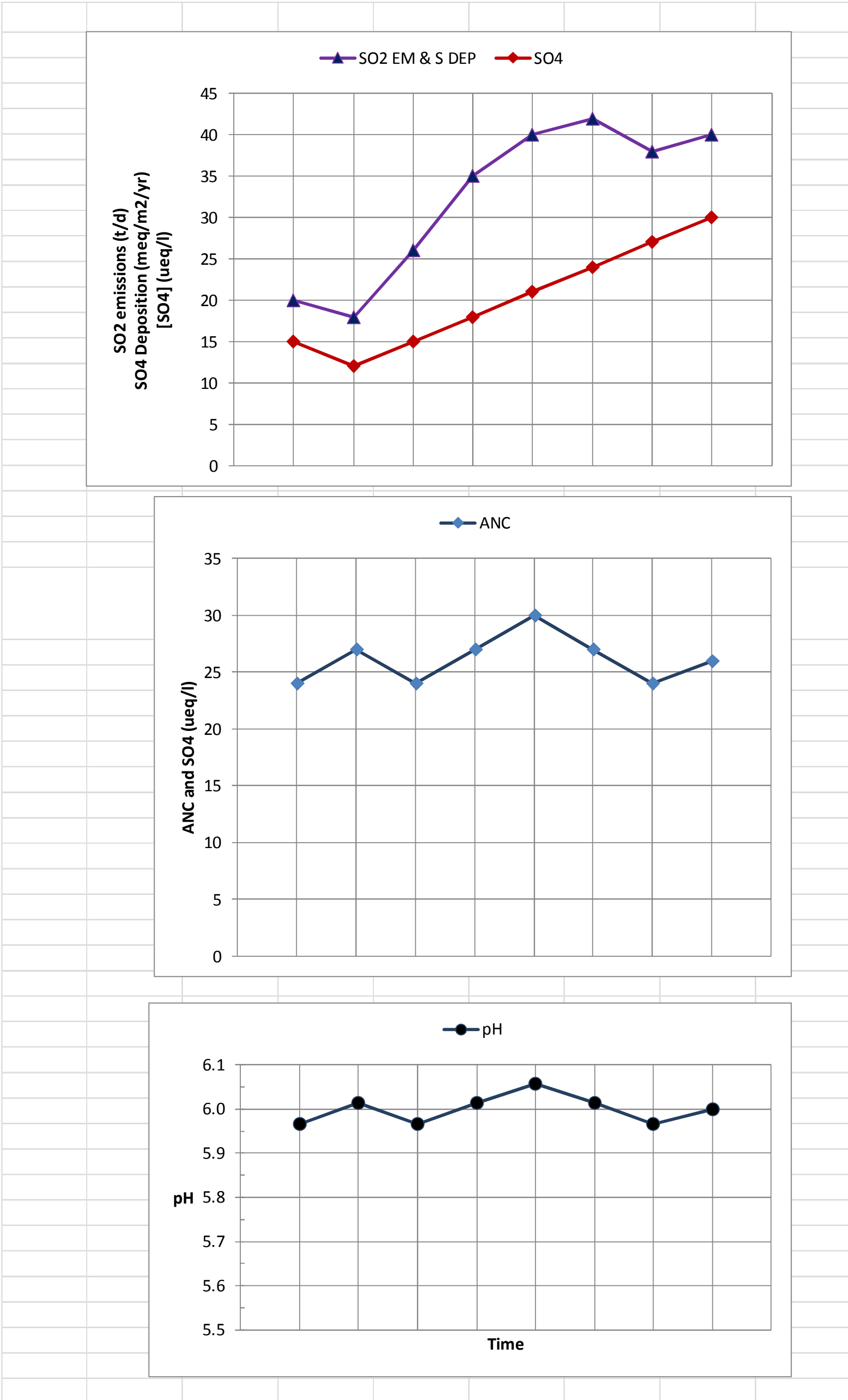

Figure 11. Patterns of changes in SO_4 deposition (top graph), lake [SO_4] and ANC (middle graph), and lake pH (bottom) indicating no acidification (i.e., lake [SO_4] increases, but sufficient weathering rates to neutralize deposited acids, so no change in ANC or pH).

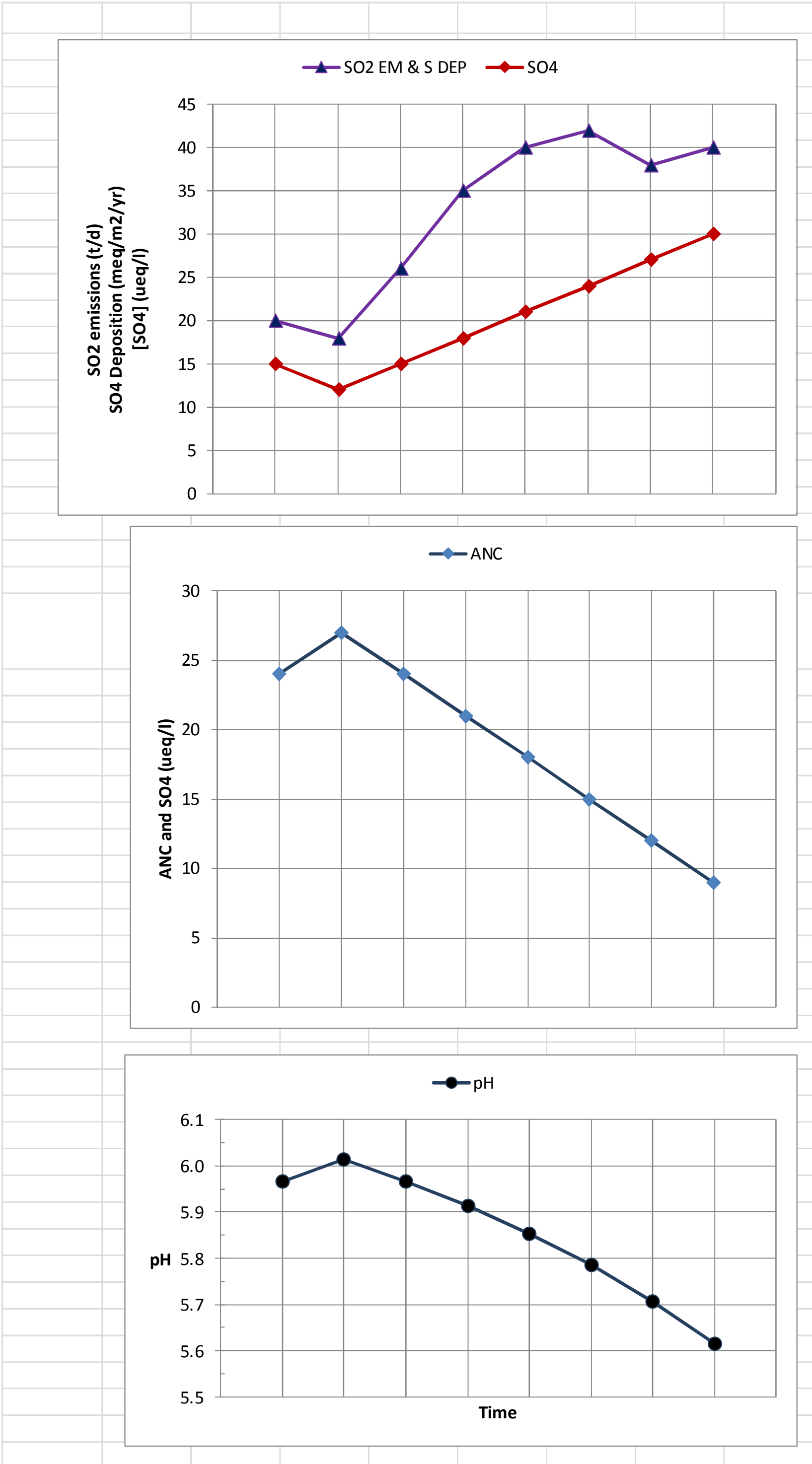

Figure 12. Patterns of changes in SO_2 emissions, SO_4 deposition and lake [SO_4] (top graph), ANC (middle graph), and lake pH (bottom graph) consistent with acidification due to KMP.

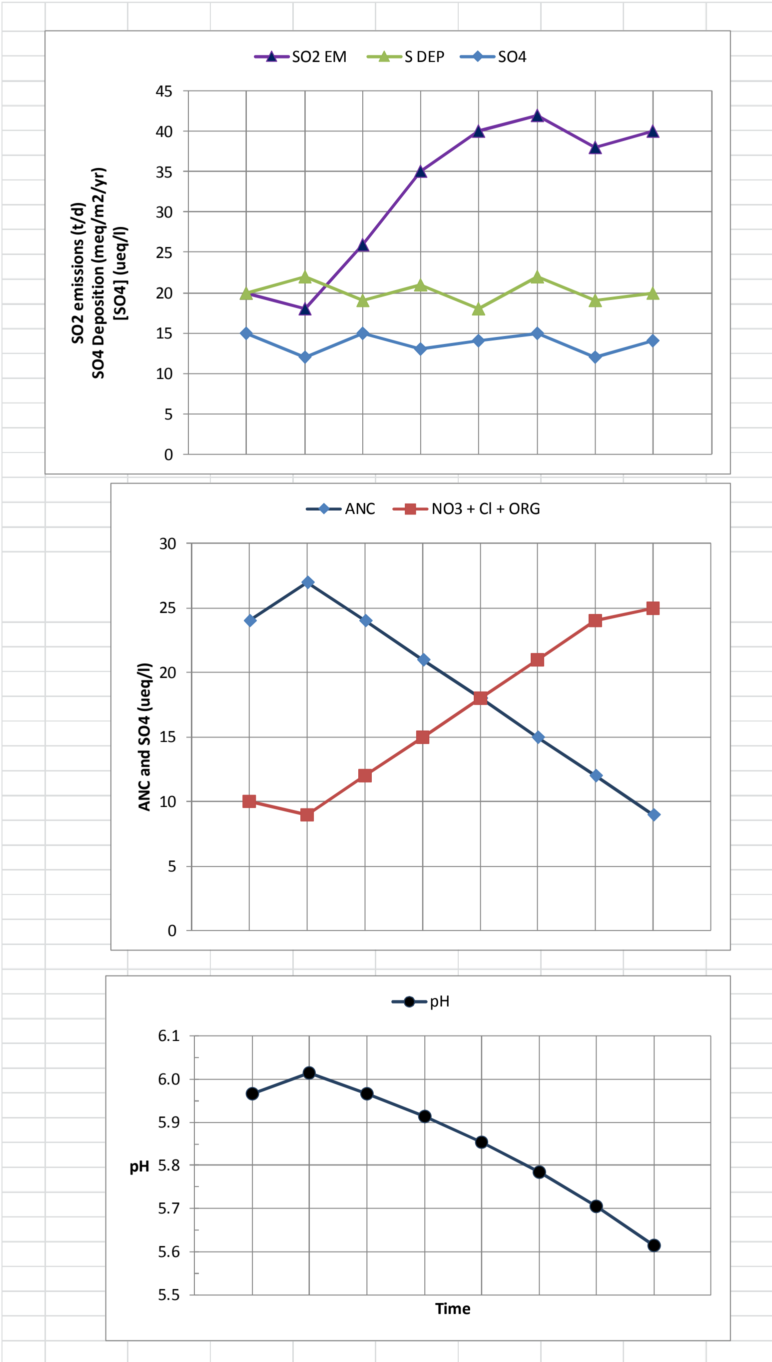

Figure 13. Patterns of changes in SO_2 emissions, SO_4 deposition and lake [SO_4] (top graph), ANC and other anions [NO3+CL+Organic], (middle graph); and lake pH (bottom graph) consistent with acidification due factors other than KMP (i.e., N emissions, sea salt acidification, and/or climate-driven releases of organic anions). This pattern might occur for high DOC lakes close to the sea but far from the smelter plume and therefore receiving low levels of S deposition.

Table 26. Characteristics of lakes included in the EEM Program. Chemical values shown are from sampling in August 2012. EEM Program will rely on fall sampling.

IDENTIFICATION		SITE ATTRIBUTES							ANION COMPOSITION					CRITICAL LOAD, DEPOSITION & EXCEEDANCE				pH (original, present, post-KMP)			
Lake/Stream ID	Name	Elevation	Lake Area	Watershed Area	Runoff	Acid Sensitivity Class (ASC) [1]	Fish Habitat [2]	Gran ANC	HCO_3	Cl	SO_4	ORG	F	Critical Load	SDEP [5] (pre-KMP)	SDEP [5] (post-KMP)	Exceedance	Estimated original pH	Measured current pH	Predicted future steady-state pH	Predicted Δ pH (2012 to future)
		m	ha	ha	m			µmeq/L	%	%	%	%	%	meq/m²/yr	meq/m²/yr	meq/m²/yr	meq/m²/yr	pH_0	pH_t	pH_∞	
Acid Sensitive Lakes																					
LAK006	End L.	151	10.2	91	0.9	3	Yes - Obs.	25.7	34%	8%	17%	34%	6%	28.4	20.7	42.4	14.2	6.02	5.79	5.31	-0.48
LAK012	Little End L.	151	2.3	90	0.9	3	Yes - Obs.	57.0	61%	4%	6%	26%	4%	79.1	19.9	41.5	-37.4	5.74	5.64	5.51	-0.13
LAK022		162	5.7	40	0.8	3	Yes - Infer.	27.8	24%	7%	29%	35%	6%	53.9	19.5	41.5	-12.2	6.11	5.92	5.54	-0.39
LAK023	West L.	211	6.8	40	0.9	3	Yes - Obs.	19.8	25%	6%	25%	36%	7%	31.9	20.3	40.7	9.0	5.96	5.70	5.16	-0.54
LAK028		267	1.0	12	1.6	4	Unknown	-4.0	0%	5%	51%	25%	18%	46.1	63.7	96.8	51.2	5.77	4.98	4.60	-0.38
LAK042		171	1.5	37	0.6	1	Yes - Infer.	-20.4	0%	7%	8%	81%	4%	15.9	6.7	15.7	0.2	4.92	4.68	4.48	-0.20
LAK044	Finlay Lake	219	2.0	10	0.6	1	No - Obs.	1.3	9%	19%	24%	38%	10%	0.0	7.0	16.6	16.7	5.80	5.40	4.86	-0.55
Control Lakes																					
LAK007	Clearwater Ls.	152	2.6	367	1.0	3	Yes - Obs.	1437.6	95%	2%	3%	0%	0%	1390.0	16.8	35.9	-1353.7	7.98	7.98	7.98	0.00
LAK016		247	2.6	41	0.9	3	Unknown	68.7	53%	4%	23%	15%	5%	115.5	21.9	44.3	-70.9	6.37	6.31	6.24	-0.07
LAK034		292	8.6	73	0.7	3	Yes - Infer.	99.4	69%	3%	11%	15%	3%	125.1	8.0	18.8	-105.9	6.76	6.74	6.71	-0.03
Special Study Streams																					
STR002	Anderson Cr. d/s	146		3741	2.1	3	Yes - Obs.	94.2	57%	2%	37%	3%	1%	330.6	21.4	25.5	-301.9	6.91	6.91	6.91	0.00
STR009	Kitimat R. d/s	112		157136	1.6	3	Yes - Obs.	160.6	80%	4%	13%	2%	0%	299.3	13.9	23.6	-273.4	6.98	6.98	6.98	0.00

Table 27 shows examples of pH, ANC and SO_4 thresholds that will be determined for each of the 7 acid-sensitive lakes in the EEM Program, based on a lake specific titration curve derived from the Gran ANC calculations. The titration curve is the relationship between pH and ANC, and its shape is affected by the amount and character of dissolved organic acids in a lake (ESSA et al. 2013 (pgs. 238-239, 304), Hemond 1990, Marmorek et al. 1996).

Table 27. Illustration of pH, ANC and SO_4 thresholds which would be established for each of the 7 acid-sensitive lakes in the EEM Program, based on lake specific titration curves. Exceeding SO_4 thresholds is not a concern as long as the pH and ANC thresholds are not exceeded. The calculation of the Baseline value is discussed in Section 6.2.2.

Hypothetical Lake	**pH**			**ANC**			**SO_4**		
	Base-line value	Threshold Value	Threshold Δ	Base-line value	Threshold Value	Threshold Δ	Base-line value	Threshold Value	Threshold Δ
A	6.0	5.7	0.3	26	11.8	-14.2	30.2	44.4	14.2
B	5.5	5.2	0.3	5.8	-1.1	-6.9	6.2	13.1	6.9
C	5.0	4.7	0.3	-5.8	-15.6	-9.8	56.9	66.7	9.8
D	4.5	4.2	0.3	-26	-53.2	-27.2	9.0	36.2	27.2

Determining whether or not an individual lake's fall pH measurement has decreased by 0.3 units (Table 14 trigger for increased monitoring) involves comparing baseline estimates of the pre-KMP pH with post KMP pH measurements. Combining all of the data for the seven acid-sensitive lakes will increase the sample size 7-fold for detecting overall trends in pH, ANC and SO_4.

Comparisons of lake pH values will be affected by variability in pH both between years (due to annual variation in climate) and within the fall sampling period (due to variability in lake productivity, mixing and weather). Ultimately there are two potential types of errors:

1. *False negative:* not detecting a real pH decrease of 0.3 units that has occurred, could affect aquatic biota, and is due to KMP (an environmental risk); and
2. *False positive:* detecting a pH change of 0.3 units which is actually due to natural fluctuations and falsely attributing it to KMP, leading to unnecessary expenditures on monitoring and/or mitigation (an economic risk).

The EEM Program will use five strategies to reduce the risks of these errors:

1. examine long term data sets from other regions of North America to assess within-year and between-year variability in lake chemistry;
2. obtain estimates of the natural variability in pH, ANC, SO_4 and other ions from 3 of the acid-sensitive lakes (End Lake (lake 006), Little End Lake (lake 012), and West Lake (lake 023))[35];
3. use inferences from steps 1 and 2 to conduct statistical power analyses of the ability to detect changes in pH, ANC and SO_4 over different time frames, using either fall index samples or more frequent sampling, building on the work of Stoddard et al. (1996), excerpted in Figure 16;
4. use data from all 7 acid-sensitive EEM lakes jointly to increase statistical power;
5. examine patterns of change in lake chemistry across gradients of SO_4 deposition and sensitivity within the 11 sampled lakes (7 acid-sensitive and 4 insensitive lakes); and
6. use multiple lines of evidence to assess whether or not acidification is occurring (i.e., lake pH, ANC, SO_4, NO_3, DOC, S and N deposition), as discussed above.

Step 1 has been partially completed and provides some useful insights. Further work is planned in 2014. The 7 acid-sensitive lakes in the EEM Program all have pH values less than 6 (pH ranges from 4.7 to 5.92). Figure 14 shows that within year variability in pH in Ontario lakes was much less for lakes with a mean pH<6, than for lakes with a mean pH>6. These results reflect two factors: 1) pH is on a log scale, so a given change in hydrogen ion concentration results in a smaller pH change below pH 6 than above pH 6; and 2) lakes with pH < 6 are generally less productive than lakes with pH > 6 and therefore have less within-year variability in pH. Figure

[35] Continuous pH monitors (calibrated and cross-checked against a field pH meter every two weeks) will record pH every 30 minutes from September 2014 to August 2015 except during winter months when ice cover prevents access. Full chemistry samples will be obtained four times during October 2014 to assess natural variability during the index period, and monthly during other months except for the winter period.

14 provides encouragement that a year on year change of > 0.3 pH units will generally be greater than within year variability in pH for the EEM lakes, and therefore more feasible to detect. Furthermore, variability within the fall index period is likely to be less than variability within the entire year.

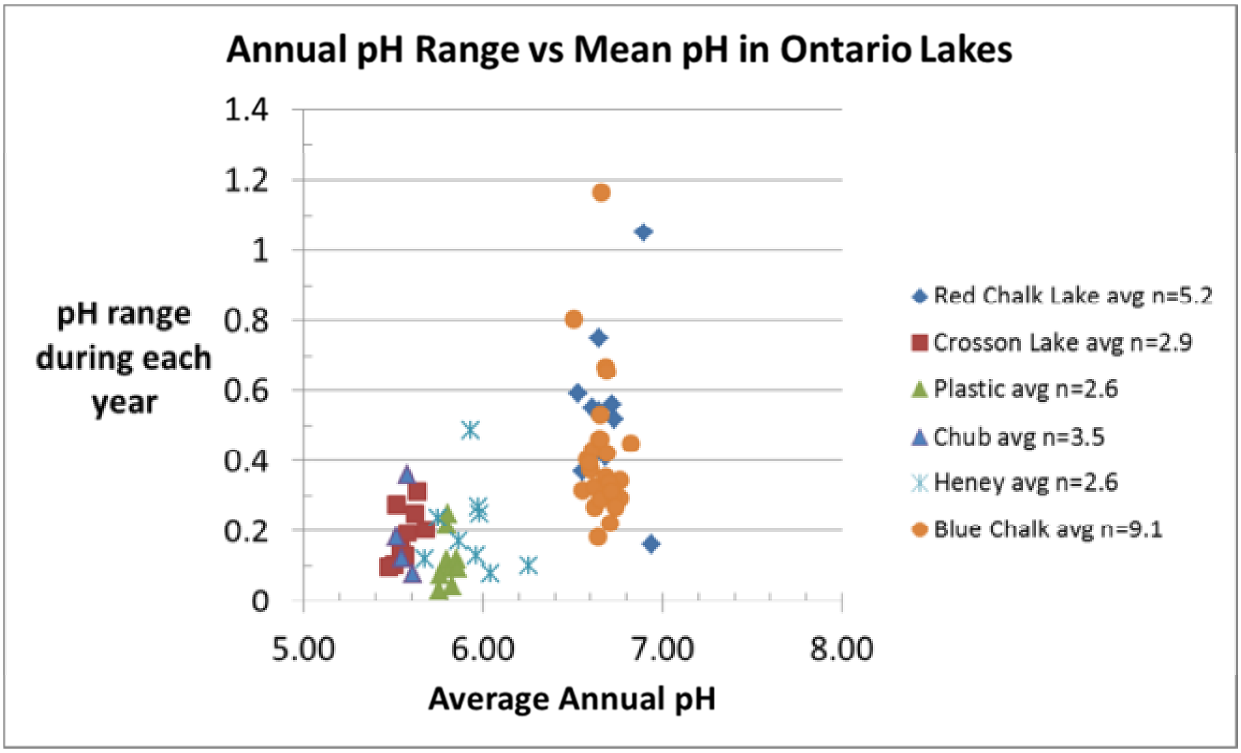

Figure 14. Within year range of pH (maximum pH – minimum pH) versus mean annual pH, for 63 lake-years of data from Ontario lakes. For lakes with an annual mean pH < 6, the pH range was less than 0.3 pH units for 27 out of the 31 lake years of data. Source of data: Dr. Norman Yan (York University) and Andrew Paterson (Ontario Ministry of Environment).

Figure 15 is from 32 years of monitoring data for Blue Chalk Lake in Ontario, which over the period from 1976 to 2007 had an average pH between 6.4 and 6.8, and a slightly increasing trend. Since the mean pH of Blue Chalk Lake was greater than 6, it had more variability in pH than Ontario lakes with a mean pH < 6 (Figure 14) and more variability than we would expect to observe in the 7 EEM lakes, which all had a pH < 6 in August 2012. Figure 15 shows that October pH samples in Blue Chalk Lake generally tracked the overall trend in pH over this period, and showed less variability than the complete data set. Similar analyses of variability in long term monitoring data led the US EPA to select the fall index period for lake sampling in the National Surface Water Survey (Landers et al. 1987), and the subsequent Environmental Monitoring and Assessment Program (Stoddard et al. 1996).

The work by Stoddard et al. (1996) on behalf of the US EPA is very relevant to the KMP EEM Program. Stoddard et al found that annual sampling of 5 low ANC-low DOC lakes (top curve of top graph in Figure 16) could detect an annual ANC trend of 0.5 µeq L^{-1} yr^{-1} at high statistical power (0.8) after 10 years, or a total change in ANC of 5 µeq L^{-1} after 10 years. Though Stoddard et al. do not present curves for other effect sizes, it should take less time to reliably detect larger ANC changes. As shown in the example of Table 27, the KMP EEM Program needs to detect ANC changes in the range from 7 to 27 µeq L^{-1}, which are larger than the decadal changes of 5 µeq L^{-1} assessed by Stoddard et al. These results suggest that it should be feasible to reliably detect the desired ANC changes in less than a decade for the complete set of EEM lakes, but this preliminary observation needs to be confirmed in the statistical power analyses to be conducted based on data gathered in 2014.

Trends in SO_4 (bottom graph in Figure 16) can be reliably detected sooner than trends in ANC (top graph in Figure 16), as SO4 is less variable than ANC. Stoddard et al. found that it would take only 5 years to detect an annual trend in SO4 of 1.2 µeq L^{-1} yr^{-1}, or 12 µeq L^{-1}per decade (at the low end of the range in Table 27); smaller changes in SO_4 would be detectable with high statistical power after a decade of monitoring.

The data for all 7 acid-sensitive lakes could also be analyzed using an approach like that in Figure 17. This would provide an estimate of the proportion of the complete sample of all acid-sensitive lakes which show pH changes beyond the specified threshold. A similar approach could be applied to ANC and SO_4. As shown in Figure 16, the 7 acid-sensitive lakes should provide a sufficient sample size for the population of interest.

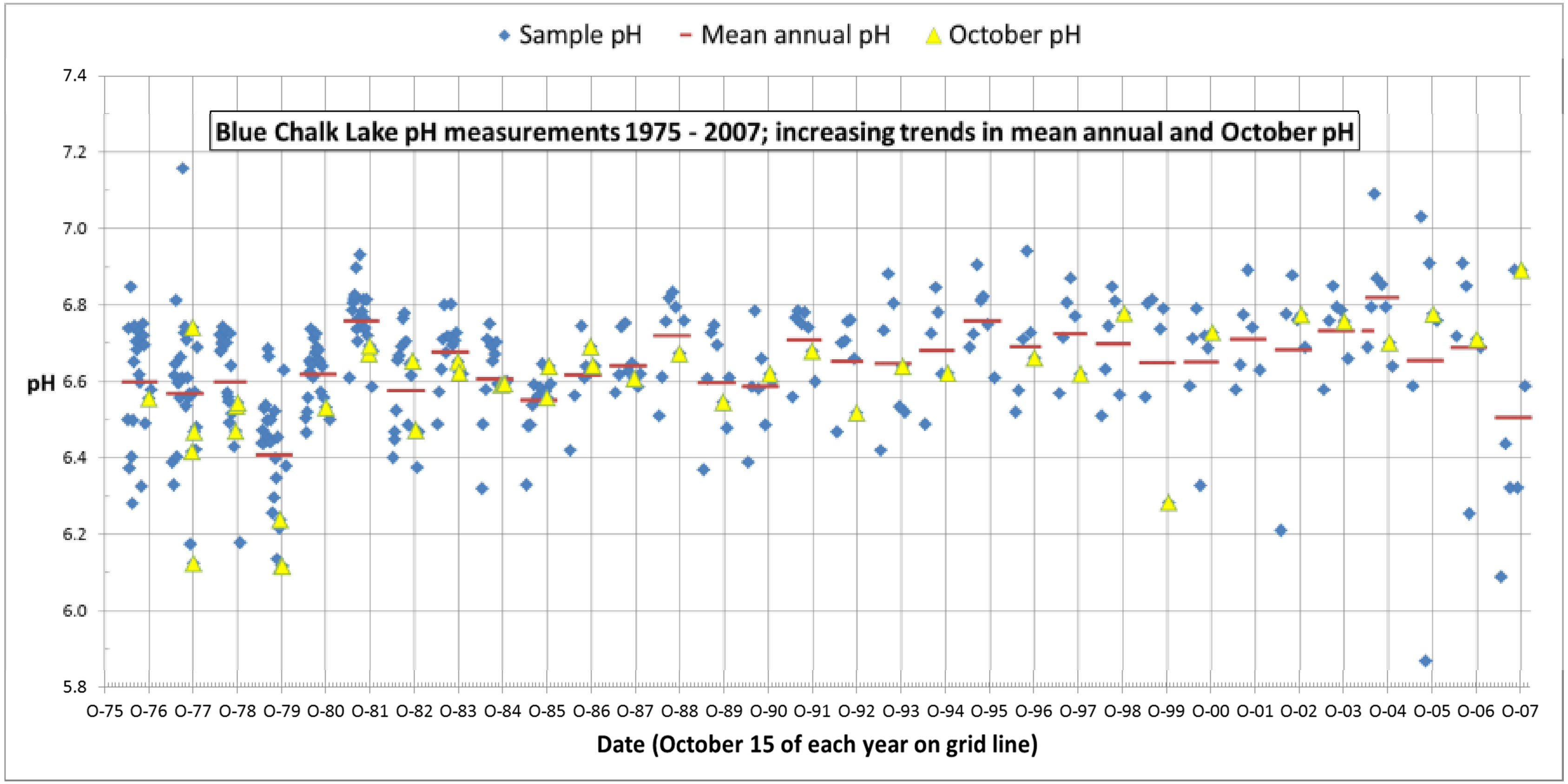

Figure 15. Long term trends in pH in Blue Chalk Lake in Ontario. All sampled pH values are shown by the blue diamonds. October pH samples (coinciding with the vertical grid lines) are shown by the yellow triangles. The mean pH for each year is shown by the red bars for each year.

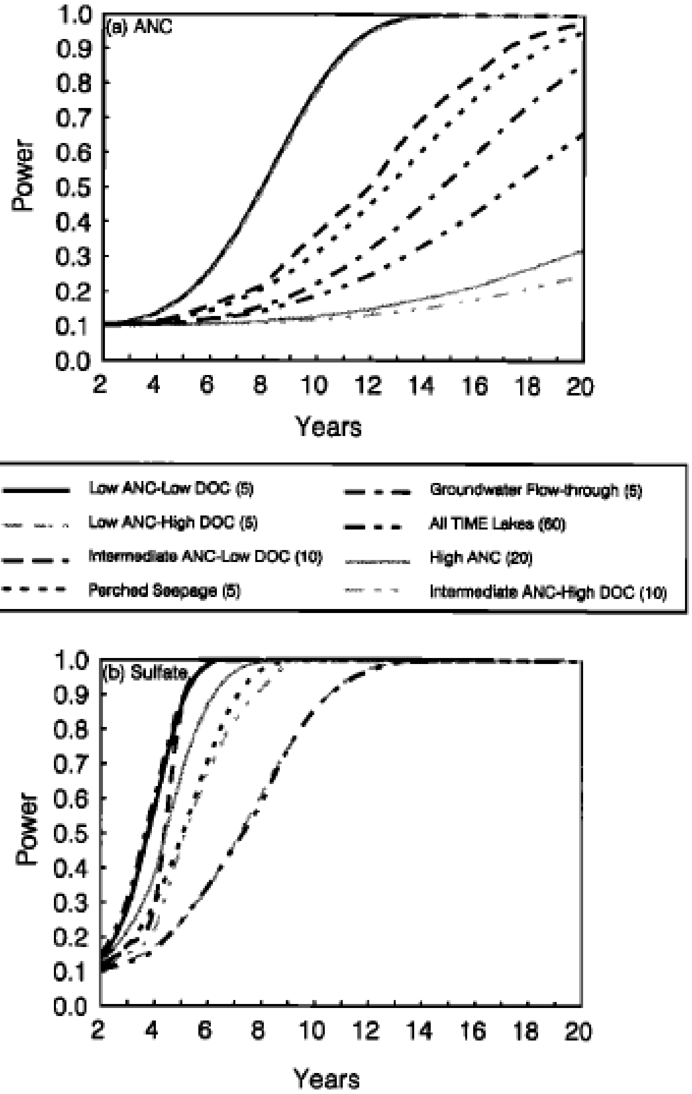

Figure 4. Results of power calculations for seven TIME subpopulations and all TIME lakes for trends in (a) ANC ($\Delta = 0.5$ $\mu eq\ L^{-1}\ yr^{-1}$) and (b) SO_4^{2-} ($\Delta = 1.2$ $\mu eq\ L^{-1}\ yr^{-1}$). In both plots, $\alpha = 0.10$. For ease of interpretation, lake subpopulations are listed in the legend in decreasing order of power for ANC trends (power curves for the low-ANC/low-DOC and low-ANC/high-DOC subpopulations are nearly coincident and plot together). Numbers in parentheses in legend are the annual sample sizes used in the calculations for each subpopulation.

Figure 16. Statistical power analyses for detecting changes in lake ANC and SO. Source: Figure 4 in Stoddard et al. (1996).

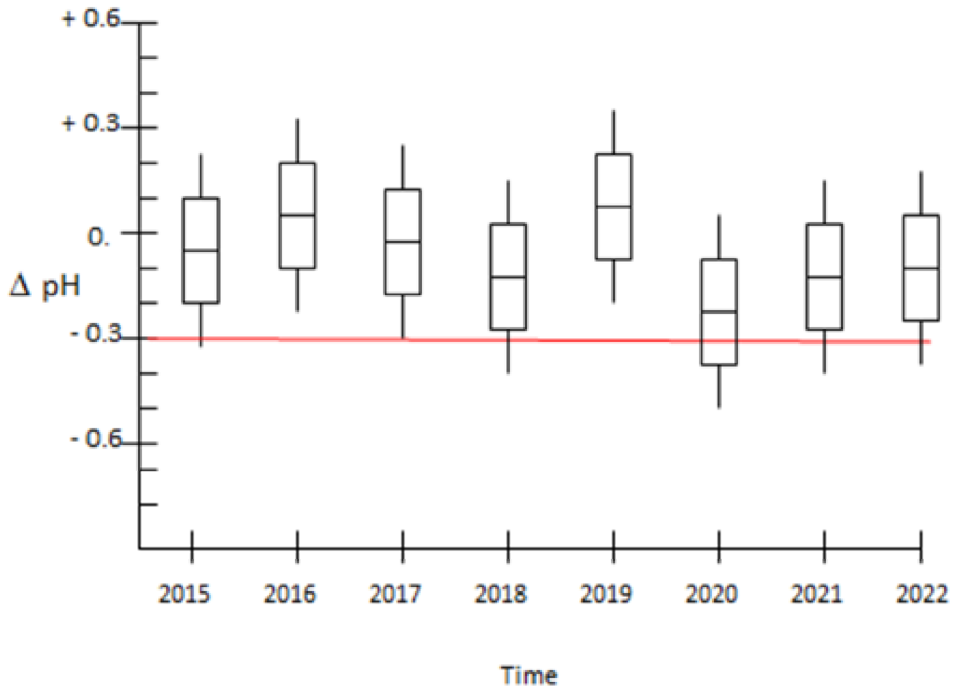

Figure 17. Illustration of hypothetical regional trends in the distribution of pH changes across the set of 7 EEM lakes.

A similar graph could be generated for other parameters (ANC, SO, base cations). From 2015 onwards, the pH measurements from each of the seven acid-sensitive lakes would be compared to the mean pH for each lake from the baseline period (discussed in Section 6.2.2). The box represents the distribution of the middle 50% of such comparisons of pH change (i.e., 25th to 75th percentiles), and the tails represent the 10th to 90th percentiles. These data could be used to determine the proportions of pH changes in any one year (across all lakes) that are less than -0.3. Water quality data from multiple lakes (pH, ANC, SO, base cations) could also be analyzed using a linear mixed-effects model having lakes and years as class variables (equation 1 in Stoddard et al. 1996).

References:

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants, and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Volume 2: Final Technical Report. Prepared for Rio Tinto Alcan, Kitimat, B.C. 450 pp.

Hemond, H.F. 1990. Acid Neutralizing Capacity, Alkalinity, and Acid-Base Status of Natural Waters Containing Organic Acids. Environ. Sci. Technol. 24:1486-1489.

Marmorek, D.R., R.M. MacQueen, C.H.R. Wedeles, J. Korman, P.J. Blancher, and D.K. McNicol. 1996. Improving pH and alkalinity estimates for regional-scale acidification models: incorporation of dissolved organic carbon. Canadian Journal of Fisheries and Aquatic Sciences 53: 1602-1608.

Stoddard, J. L., A. D. Newell, N. S. Urquhart, and D. Kugler. 1996. The TIME project design: II. Detection of regional acidification trends. Water Resources Research 32:2529-2538.

Stoddard, J.L., J.S. Kahl, F.A. Deviney, D.R. DeWalle, C.T. Driscoll, A.T. Herlihy, J.H. Kellogg, P.S. Murdoch, J.R. Webb, and K.E. Webster. 2003. Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990. EPA 620/R-03/001. US Environmental Protection Agency, Office of Research and Development. National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC 27711. 92 pp.

Appendix I. Liming Treatment to Mitigate Acidic Effects on an EEM Study Lake: Conceptual Design of Pilot Study

Context

If the KPIs for lakes, streams and aquatic biota exceed the threshold for receptor-based mitigation, the prescribed action is:

> "Pilot liming to bring the lake back up to pre-KMP pH, subject to approval by BC MOE/DFO prior to implementation"

In the case that an exceedance of the KPI has been observed, measured and concluded to be real (i.e., not a false positive), the following section provides an outline of the approach for designing a pilot study for liming.

Objectives

Objectives of the Liming Treatment

1. Restore lake pH to its pre-acidification chemical condition without causing adverse ecological impacts

Objectives of the Pilot Study

2. Determine the optimum method of liming.
3. Determine the chemical effects of the liming treatment on the target lake
4. Determine the biological effects of the liming treatment on the target lake

Hypothesis

The pilot study will be designed to be able to evaluate whether the evidence supports or fails to support the following hypothesis:

> *Liming treatment will restore lake chemistry (i.e., pH and ANC) without causing adverse effects to biological functioning of the lake ecosystem.*

Candidate Lakes for Limestone Treatment

The lake or lakes being considered as candidates for limestone treatment will be those that have exceeded the KPI thresholds for receptor-based mitigation, as per the design of the EEM. *There will be **two lakes at most** under consideration* for limestone treatment because any more than two lakes would trigger the requirement for facility-based mitigation.

Suitability Criteria

The best candidates for liming (Weigmann et al. 1993) have the following characteristics:

- Softwater lakes with pH < 6.5;
- Large pH fluctuations;
- Retention time > 3 months;
- Evidence of historical fish populations; and
- Slow fish growth and low food production.

Additionally, the candidate lake needs to be safely accessible, both for treatment and monitoring purposes. Ideally, it will be easily accessible to facilitate repeated monitoring visits before and after treatment.

Methods

Initial analyses

A number of analyses will need to be conducted before implementing a pilot liming treatment.

1. The candidate lake(s) must be assessed in terms of its suitability for treatment.
2. A benefit-cost analysis of liming treatment options will be needed to inform the design of the pilot study (e.g., accessibility will influence the treatment methods, such as surface or aerial application, and the cost of repeated monitoring).
3. The amount of limestone to be applied in the treatment in order to achieve the target increase in pH will be calculated (i.e., based on the physical properties of the lake and the lake-specific titration curve).
4. A conservative, incremental approach will be designed for the application limestone to ensure the pH target is not exceeded.
5. The full experimental design of the pilot study will be finalized, with additional review by:
   a. Limestone treatment expert – to ensure the treatment has the highest probability of being successful; and,
   b. Statistical design expert – to ensure the study has ability to correctly detect changes in lake chemistry and biology (e.g., power analyses).

Pre-liming sampling to establish chemical and biological baseline

Baseline sampling must be conducted prior to application of the limestone to be able determine the impacts of the liming treatment on lake chemistry and biology.

Water chemistry: The pre-liming baseline for water chemistry conditions will be established by the annual EEM fall index sample. This sample includes full chemistry (pH, ANC, base cations, anions, Al and other metals, as described for annual monitoring in the EEM.

Lake biology: The pre-liming baseline for lake biological conditions will be established by sampling phytoplankton, zooplankton, and fish communities to estimate biomass, density and diversity. Establishing a robust baseline for phytoplankton and zooplankton will require six monthly samples from May to October, obtained from near the middle of the lake in the pelagic zone. Additional baseline monitoring could include estimating zooplankton productivity and/or sampling macrophyte biomass, coverage and diversity; however, further evaluation is required to assess their utility for achieving the objectives of the pilot study.

<u>Buffer compound</u>

Calcite (agricultural limestone) is the most commonly used liming compound (Clair and Hindar 2005). It is relatively inexpensive, widely available, natural, non-toxic and easy to work with (Weigmann et al. 1992). Dolomite limestone is chemically similar, with slightly higher buffering capacity but lower solubility, but an acceptable alternative when calcite is not readily available (Weigmann et al. 1992). Numerous other liming compounds exist but most have only been used experimentally or are difficult to work with (Clair and Hindar 2005).

<u>Application of liming treatment</u>

Given the small size of the lakes of interest in the KMP study area, application of a limestone slurry from a tank onboard a boat would be the most cost-effective approach for road-accessible lakes, which ensures both rapid dissolution and accurate delivery across the lake surface (Olem 1990, pg. 15-59). Delivery of limestone by helicopter or fixed wing aircraft would be the only option for lakes which are not accessible by road, and the pros and cons would need to be carefully evaluated (e.g., safety, lake's value, degree of pH control); these methods have had mixed success (Olem 1990, pg. 15-61 to 15-63).

<u>Post-liming chemical and biological monitoring</u>

After the application of the limestone treatment, monitoring of water chemistry and lake biology would occur annually for three years, following the same approach as described above for pre-liming monitoring (i.e., fall index sampling for chemistry, six monthly samples for biology). At that point, the chemical and biological effectiveness of the program would be evaluated, and decisions made regarding future monitoring.

<u>Analyses of pre- and post-liming monitoring data</u>

Pre- and post-liming monitoring data would be compared and analyzed in order to determine the impacts of the limestone treatment on lake chemistry and biological conditions and assess the statistical and biological significance of those impacts.

Documentation and reporting

Documentation of the study design for the pilot limestone treatment, preliminary analyses, treatment implementation, monitoring results, and subsequent analyses would be reported within the annual EEM reporting framework.